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UNIVERSITY OF ALBERTA

MATERIAL MOVEMENT IN THE THRESHING SECTION OF AN
AXIAL-FLOW COMBINE

by

ANIL K. KUKREJA



A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND
RESEARCH IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE

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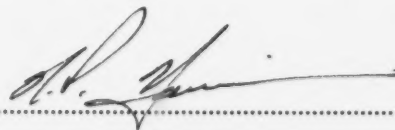
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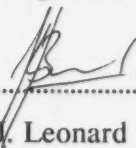
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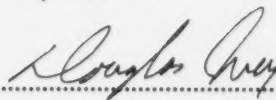
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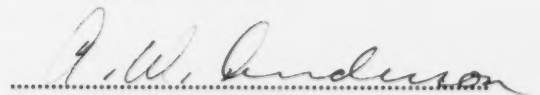
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ABSTRACT

An inexpensive system to measure the axial and rotational (tangential) velocity of a crop, as it is transported by the rotor of an axial-flow combine, was developed. The system was based on using an array of magnetic-field sensors with a magnet propelled past it with the crop material. Sensor selection and data acquisition is detailed. System components were cheap but required much labour to assemble.

A block experiment with three transport vane angles and two levels of rotor speed was replicated three times for a total of 18 runs. The concave and vane traverse of the crop was identified by plotting the triggered sensors in three dimensions. The absence of a few triggered sensors due to breaking and crushing of magnets made it impossible to define the axial displacement in a number of instances and thus created a situation of missing data.

The mean axial velocity of the crop as it traversed the concave and vanes was between 1.6 and 1.7 m/s and the rotational velocity was approximately 1/3 to 1/5 of the peripheral velocity of the rotor. The accuracy in determining the mean crop velocities in an axial-flow combine was a function of the number of sensors per row and the number of rows.

The experimental factors of vane angle and rotor speed did not test significant due to large random variations in the data and the missing data. It followed that the technique is unsuitable to discern the small but crucial differences in velocities caused by small changes in the vane angle and rotor speed.

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ADIOS !

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List of Symbols

Symbol	Description	Units
a_1	Surface characteristic factor of the active guide vanes	
a_2	Air stream flow factor	
AC	Alternating current	amp
d_{ax}	Distance between two consecutively triggered sensors	m
DAS	Data acquisition system	
DC	Direct current	
GLM	General linear model	
IH	International Harvester	
JD	John-Deere	
m_f	Material feed rate	t/h
MRS	Magneto-resistive sensor	
MEP	Maximum energy product	Guass-Oersteds
NH	New-Holland	
PCB	Printed circuit board	
PTO	Power take-off	
RAM	Random access memory	
RE	Rare earth	
RPM	Revolutions per minute	1/min
SAS	Statistical analysis system	
S_{ax}	Axial displacement of the material for one revolution of the rotor	m
V_{ax}	Velocity of the material along the rotor axis	m/s
V_{mat}	Absolute velocity of the material	m/s

V_r	Relative speed of the material wrt active guide elements	m/s
V_R	Peripheral speed of the rotor	m/s
V_{tan}	Velocity of the material perpendicular to the rotor axis (rotational)	m/s
α	Helix angle of the passive guide vanes	degrees
β	Helix angle of the active guide vanes	degrees
τ	Angle of the material movement	degrees
μF	Micro-farads	
δ	Net co-efficient of slip	

1. INTRODUCTION

1.1 ROTARY COMBINES :

A recent addition to grain harvesting technology has been the threshing rotor of an axial-flow combine (Harrison 1989). The major differences in the cylindrical (conventional) and the rotary (axial-flow) combines are the change in the pathway of the crop from an arc to a helix (Lamp and Buchele 1964), and the replacement of the straw walkers with a centrifugal separator (Long et al. 1967). Wacker (1985) notes the simplicity of mechanism and higher capacity of the axial-flow combines over the conventional as reasons for the interest in these combines.

The threshing and separation are accomplished in the same area of the machine with the rotor. Since the material moves in a spiral path, the effect is a longer path of travel thereby rotor providing more time and work for threshing (Wacker 1985).

There are several rotary combine models available on the market today. About 20 years ago, a few manufacturers chose the axial-flow concept with rotor(s) to be an answer to the ever-growing combine design problems in conventional types having cylinder(s) and straw walkers as working elements. The increased width and height of higher capacity conventional combines caused transportation problems in some European countries and also in North-America where most combines are delivered by railway to the retailer from the manufacturer. According to Harrison (1983), the rotary technology has not been universally endorsed by farm machinery manufacturers or their customers, but Wacker (1985) notes that they account for a substantial share of the total combines sales.

According to Quick and Buchele (1978), the rotary concept for threshing and separating has been around for a century now. Kydd (1980) reports that researchers, research institutions and test stations have shown a great interest in rotary combine technology. Most studies have however, focused on comparisons between rotary combines and conventional cylinder/straw walker combines in field conditions. Research projects with the aim of improving and/or developing rotary combine technology have been limited in the public domain.

Figure 1.1 shows a complete side view of an axial-flow combine (IH Model 1460). The material comprising of grain ears and straw enters into the threshing drum with the help of a feeding auger located at the front of the machine. The material due to the helix bars on the rotor moves in both axial and tangential direction. The threshed material passes through the concaves and is diverted onto the cleaning shoe where the fine straw is blown out. The shoe constitutes of a number of adjustable and/or fixed sieves with an oscillating mechanism and an air supply. Some of the unseparated material with the larger straw makes an exit at the end of separation concaves just before the discharge beater.

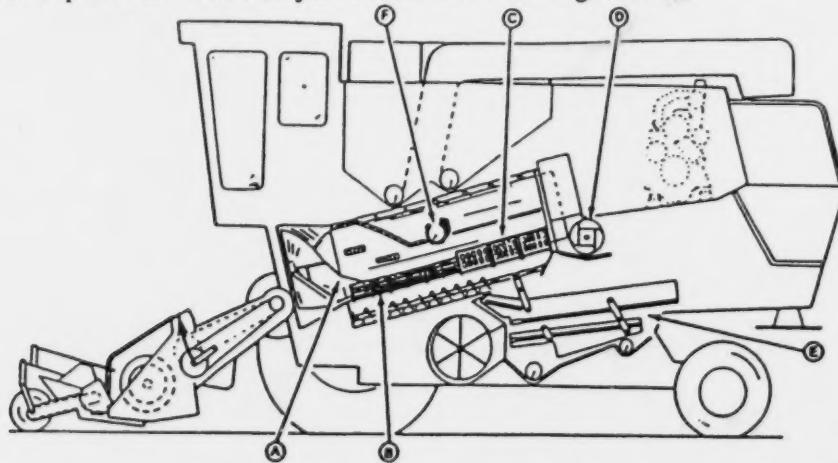


Figure 1.1 International Harvester 1460 axial-flow combine. (A) rotor, (B) threshing concaves, (C) separation concaves, (D) back beater, (E) shoe, (F) tailings return. (Adapted from PAMI, 1980).

A detailed study on the development of axial flow combines is given by Quick and Buchele (1978) and descriptions of the working elements and their respective functions in different combine types are given by Kydd (1980). The definitions of the frequently occurring terms such as, rotor, concave, concave wrap etc. are given in the ASAE publication: ASAE S343.2, 1988a.

2. REVIEW OF LITERATURE

According to Kutzbach et al. (1980) and Hall et al. (1982), a knowledge of the movement of material through an axial-flow threshing drum is essential for the optimization of the drum's design. To understand the separation of grain from chaff in a rotary combine, it is necessary to learn what takes place inside the separator itself rather than simply observing the input and the output. Several techniques, such as high speed and ultra high speed movie observations have been used to some success to measure the velocity and path of the material flow through rotary separator of a combine harvester (Hall et al. 1982). Another method is the addition of magnets to the material mat and tracing the magnet path with suitable sensors (Kutzbach and Wacker 1980).

The dominating force (centrifugal) acting on the grain in a rotary combine is much larger than the dominating force (gravity) that separates grain from straw at the straw walkers in a conventional combine (Wacker, 1985). Wrubleski and Smith (1980) noted that the principle of centrifugal separation of grain from straw is known to work, yet there was a limited amount of research conducted on centrifugal separation in rotary combines. There is a need for further studies to establish the principles of the separation process and the material velocity through the axial-flow drum both in the axial and the tangential direction.

2.1 CROP MOTION MODEL

2.1.1 Axial-flow Combines :

Material flow is guided in the threshing area through two sets of guide vanes known as Active and Passive vanes (Wacker, 1985). The combination of rub bars and discharge vanes mounted on the rotor of the combine are defined as active vanes (Figure 2.1); whereas, vanes which are mounted on the inside periphery of

the concave are called passive vanes. These are also known as guide vanes.

The active vanes move the material not only in axial direction but, also, in the tangential direction resulting in a net spiral path of the material flow (Lamp et al. 1964, Wacker 1985). The guide (passive) vanes, since they are fixed, contribute to the material flow only in the axial direction (Harrison, 1989). Figure 2.2 illustrates the path of the material in an axial-flow combine.

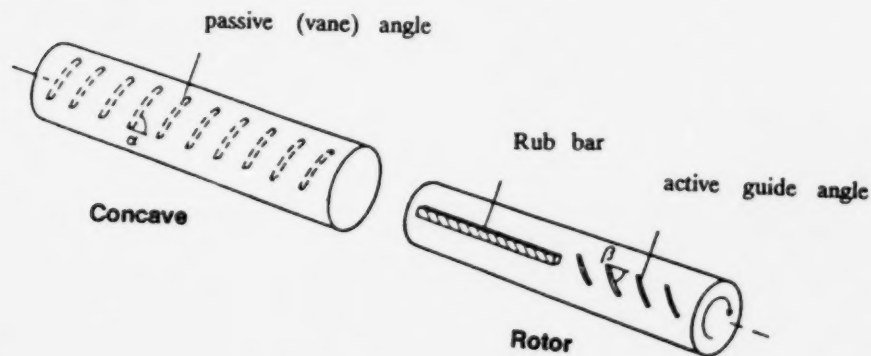


Figure 2.1 Active and passive vanes for an axial-flow combine (Adapted from Wacker, 1985).

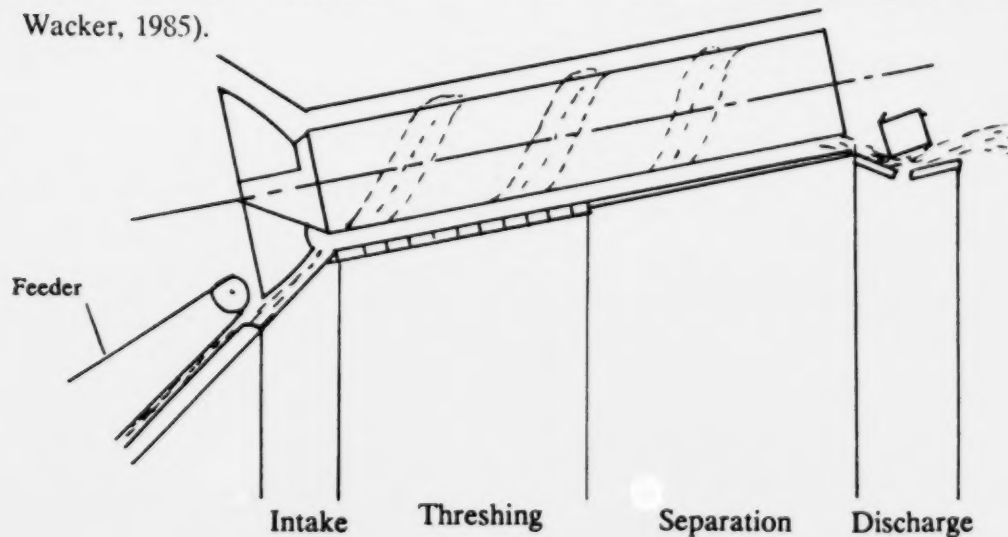


Figure 2.2 The spiralling path of the material flow (Adapted from Wacker, 1985)

In an axial flow combine the motion of the crop has two components; the velocity along the rotor axis V_{ax} and the tangential velocity V_{tan} as shown in Figure 2.3. S_{ax} is the axial displacement of the material for one revolution of the rotor, and the angle τ is the angle of the material's movement to the rotor axis such that:

$$\tan \tau = V_{tan} / V_{ax} \quad (2.1)$$

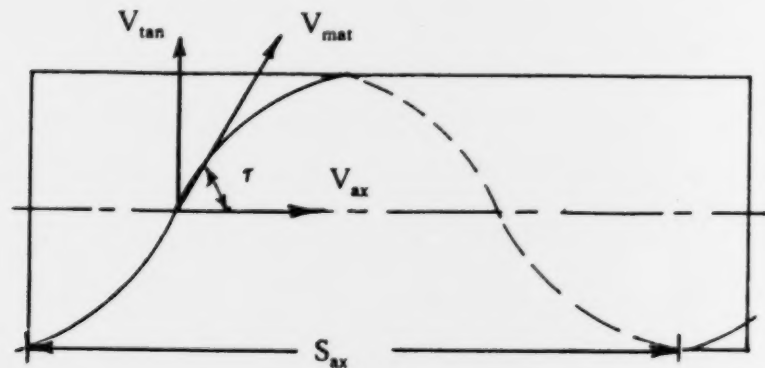


Figure 2.3 Material flow in a rotary combine (Adapted from Wacker, 1985).

The effect of active guide elements on the material velocity components is illustrated by Figure 2.4.

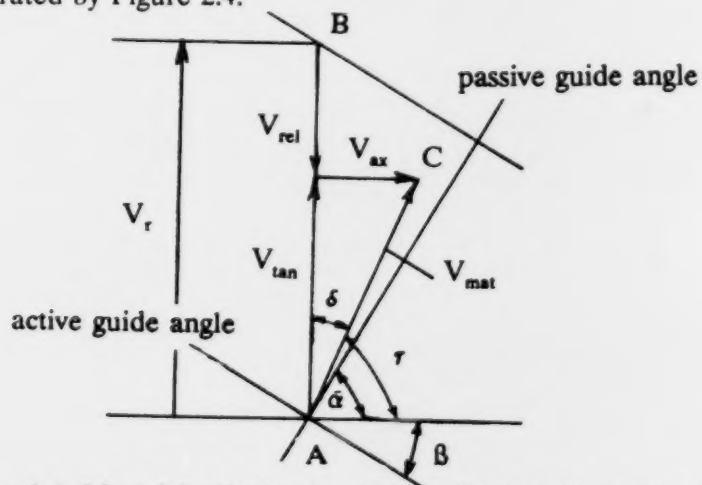


Figure 2.4 Material velocity due to an axial threshing rotor (Adapted from Wacker, 1985)

If the active guide element moves from A to B with the peripheral rotor speed of V_R , material will flow with an angle τ and the absolute velocity of V_{mat} to the point C in Figure 2.4. δ is the coefficient of sliding (slip) of the material on rotor. The material has a speed V_{rel} , relative to the active guide elements; that is,

$$V_{rel} = V_R - V_{tan} \quad (2.2)$$

Further, Equation 2.1 can also be written as;

$$V_{ax} = V_{tan} / \tan \tau = (V_R - V_{rel}) / \tan \tau \quad (2.3)$$

or

$$V_{mat} = V_{tan} / \sin \tau = (V_R - V_{rel}) / \sin \tau \quad (2.4)$$

The difference between the rotor and material speeds (V_{rel}) is observed to be quite high. Wacker (1985) attributes the difference to the clearances between the rotor and the vane (guide) elements, causing the material to slip. The percentage slip, relative speed (V_{rel}), and the material flow angle (τ) are all dependent on the frictional forces between the active guide elements and the material as well as between the material and the concave.

Wacker (1985) notes that the possibility of the air getting entrained into the material stream also exists particularly when the material is not fully loaded. Wacker (1985) further observes that the peripheral speed of the rotor V_R hardly effects the material flow angle. According to Wacker (1985) the influences on the material flow angle (τ) can however, be best described by the following equation.

$$\tau = 90 - a_1 - (a_2 / m_t) \quad (2.5)$$

Where a_1 is the helix angle of the serrations on the active guide vanes and their surface characteristics. Thus, if active guide vanes are parallel to the rotor shaft,

a_1 equals 0. The term a_2 is the effect of the air stream flow entrapped within the material and m_f is the material feed rate.

Wacker (1985) states that a_2 is influenced by a_1 and both these factors are interdependent. The effect of a_2 , the air stream flow factor, on the material flow decreases with an increase in material feed rate (m_f). The amount of air getting entrapped within the material decreases as the material feed rate increases, because of higher density (compaction).

According to Wacker (1985), passive guide elements in the concave (transport) area also effect the material flow angle τ . He further states that this effect is significantly reduced due to the concave clearances and the relatively low height of these guide vanes.

Skromme (1977) and Wacker (1985) in their analyses note that the spiralling motion of the crop makes it pass over the threshing concave and separating grate two to three times, instead of just once as in the cylinder (conventional) combine. They also note that these passes are accomplished in about one to three seconds, which is much faster than the time necessary to thresh and separate a crop in a conventional combine using straw walkers.

According to Gasperrato et al. (1989), Kutzbach (1983) and Wacker (1985), the rotational (tangential) speed of the crop is about one third that of the rotor rasp bars. Gasperrato et al. used a high-speed movie cameras to observe the material flow and to do so, removed the bonnet covering the upper part of the cylinder where guide vanes were mounted. Consequently, only rotor/concave motion was obtained. Kutzbach (1983) studied the crop motions in both a cylinder combine with straw walkers and in a rotary combine. His results as those listed in Table 2.1 and Table 2.2 could be adapted to most combines even though the sizes of the combines he studied are not given.

Table 2.1 Properties of a Cylinder/Straw Walker Combine (adopted from Kutzbach, 1983)

	unit	at cylinder	straw walker
average crop velocity	m/s	5-9	0.4-1.0
displacement of crop	m	0.5-0.8	3.5-4.4
Exposure time	s	0.05-0.15	5-10
Number of impacts on crop		5-15	15-40
Impact frequency	Hz	85-130	2.5-6.0
Straw mass per unit area (15 t/h MOG feed rate)	Kg/m ²	0.3-0.6	2.8-6.9

Table 2.2 Properties of a Rotary Combine (adopted from Kutzbach, 1983)

	unit	at threshing concave	at separating grate
Average crop velocity			
- tangential	m/s	5-11	4-10
- axial	m/s	0.1-1.6	1.3-2.0
Displacement of crop	m	5-6	4-5
Exposure time	s	0.6-0.9	0.5-0.8
Number of impacts on crop		22-40	18-35
Impact frequency	Hz	36-46	38-50
Straw mass per unit area (15 t/h MOG feed rate)	Kg/m ²	1.3-1.9	1.0-1.6

Gasparetto et al. (1989) observed from the graphical descriptions of some trajectories of grains, ears and straw that the motion of these material parts is generally uneven in an axial-flow combine. It is extremely irregular at every instant, due to collision with mechanical parts, internal rubbing and air streams which, in spite of their low energy, determine the movement of the material parts. Therefore, the grain and the ears/straw are seldom found inclined toward the theoretical direction of their movement. In fact, the trajectory of a material part can be inclined towards the right or left to the same instant often after a collision with a metal part or concave bars. He further notes that sometimes the movement of the grains happens to be contrary to the theoretical direction, and at several instances the grain remains in the air rotating around it's own centre of gravity.

3. OBJECTIVE

The overall objective of this study was to measure the axial and rotational (tangential) velocity of a crop as it is transported by the rotor of an axial-flow combine using magnetic field sensors and a dedicated data acquisition system.

The problem focuses on design and development of a suitable method with the objective of measuring the flow rapidly and without manual or visual analysis. The proposed method, a principle demonstrated by Kutzbach and Wacker (1980), involves inserting magnets in the crop material and then detecting the path of these magnets as they pass through the concave area. This path can be sensed using magnetic field sensors which are mounted along the inside periphery of the concave grates. With a variety of situations involved, the problem was sub-divided into various segments;

- selection of a suitable type of sensors,
- lay-out of the sensors for tracing magnets in an axial flow cylinder,
- specifying the data acquisition system (DAS),
- installation in an axial-flow combine at Ellerslie Research station of the University of Alberta,
- experiments and analysis of data.

3.1 PRELIMINARY DESIGN CRITERIA

The instrumentation is based on detecting small magnets which had been embedded in a plastic (heat shrink) tube (Kutzbach and Wacker 1980). Prior to threshing, the tubes are inserted into the crop windrow. The axial and rotational displacements of the magnet (or crop) are obtained by arranging sensors in a row along the concave with a sufficiently close spacing that allows the sensing of all passing magnets.

With a single row of sensors only the detection of displacement per revolution (velocity) is possible. Velocities which vary within one revolution require more sensors, the number depending on the accuracy needed. The number of sensors within a row, and the number of rows, has clear implications regarding the cost of the system and the size and complexity of the data acquisition system. That is, there is an important compromise to be made between cost and complexity in the design of the instrumentation.

The helix angles of the transport vanes in the IH 1460 combine are known to effect the axial velocity (Harrison 1989). Furthermore, there is a possibility that the axial velocity of the material in this combine may be greater than zero for only part of the rotor rotation because the vanes do not extend completely around the rotor. That is, a minimum of two rows of sensors are needed, for both ends (entry and exit of material) of these vanes. The number of sensors needed within a row is partly dependent on the sensitivity of the sensor and, therefore, cannot be specified until after a sensor has been selected.

4. SELECTION OF A SENSOR

4.1 INTRODUCTION

An evaluation of magnetic field sensors was carried out to determine the most suitable sensor for the severe environmental conditions. These severe conditions are the result of impact forces due to the threshing process for a given concave clearance. The suppression of the magnetic field for a given magnet by the presence of crop material and the metal of the concave and rotor also contributes to these poor conditions. The sensors thus designated are later to be mounted along the inside of the concave ends (at the threshing part only) of a 1978 CASE-IH model 1460, combine harvester to trace the path of passing magnets.

The speed and the path which a magnet describes inturn defines the characteristics of the material flow (Kutzbach and Walker 1980, Hall et al. 1982). Hence, a system of sensors and magnets is desired which is able to withstand all the physical stresses and the harsh environmental conditions that will be experienced by the crop material. This system should also be sensitive enough to respond to the magnetic field at various air gap lengths available between the concave grates and the crop material mat when the combine is in operation.

4.2 GENERAL CLASSIFICATION OF MAGNETIC-FIELD SENSORS

A sensor is any device that responds to or detects a physical anomaly (parameter) and transmits a signal (Anon. 1986/87). For magnetic field sensors, the physical parameter is a change in the magnetic flux density. There are two types of magnetic field sensors namely, (1) Hall-effect and (2) magneto-resistive and there are substantial differences between the two (Anon. 1989a). Hall-effect devices are semiconductors, whereas magneto-resistive devices are passive components and both transducers require a power source for operation (Anon. 1989).

4.2.1 Hall-effect based Sensor

The Hall-effect sensor in its simplest form is the Hall element. This is a thin sheet of semiconducting material with output connections perpendicular to the flow of a constant input current (Anon. 1982). When subjected to a magnetic field, the element responds with an output voltage proportional to the magnetic field strength. The addition of signal conditioning electronics makes the output usable for most field sensing applications and, once this is done, the device becomes a Hall-effect sensor. With different conditioning electronics the output can be digital. That is, a high or low output with the on-off state dependent on some designated strength of the magnetic field (Anon. 1982).

4.2.2 Magneto-resistive based Sensor

The magneto-resistive sensor (MRS) is one of the more recent developments for detecting magnetic field and its variations and, in many applications, it provides an effective alternative to the conventional Hall-effect sensor (Anon. 1985, 1988). A MRS makes use of the well known property of magnetic materials to change their resistivity in the presence of an external magnetic field (Anon. 1988, 89a). The change is known as the Guassian effect. This change in resistivity is brought about by rotation of the magnetic field relative to the current direction (Anon. 1988). An MRS is much more sensitive to slight variations in the magnetic field than a Hall-effect sensor. Thus, most manufacturers have only been producing these sensors for analog applications.

4.3 SELECTION OF A MAGNET

The selection of a magnet was based on two major criterias; (1) strength and (2) size. Both magnetic and physical strengths were taken into account when considering the strength of a magnet. Since, no guass-meter was employed in

determining the magnetic flux-density of a magnet, the Maximum Energy Product (MEP) (Gauss-Oersteds) and physical strength was noted from Anon. (1987) for some magnets. Since, the selection of a sensor also depends (discussed later) on the choice of a magnet, the selection of a magnet thus, to some degree, is also dependent on the selection of a sensor. The availability of a magnet and its cost was yet another factor in the selection of such a magnet.

The most commonly used magnets fall into the following category; Alnico, Rare Earth (RE) - cobalt, Cunife, Ceramic, Iron-chromium, Plastic and Rubber (Anon. 1987). The RE is not only the best magnet in all categories but also is one of the most expensive type (Anon. 1987). According to Anon. (1987), an Alnico magnet is a fairly expensive and stronger magnet (both physically and magnetically) but less so than the RE. Among the various alnico types, Alnico 1 to 4 are less expensive and magnetically weaker than Alnico 5 (Anon. 1987). The Maximum Energy Product in Alnico group varies from 1.3 to 10×10^6 Gauss-Oersteds which is approximately half as compared to the RE but, is approximately 10 times more than the Ceramic types (Anon. 1987).

A literature review indicated a few different types of magnets available from a local retailer. The following two types of magnets with two different sizes were purchased and tested thereafter.

- (1) **ALNICO 5** (sizes - 4 mm x 20 mm and 6 mm x 20 mm long bar magnets), and
- (2) **CERAMIC** (sizes - 6 mm x 12 mm long alongwith a 12 mm x 6 mm long bar magnet)

The chosen sensors (discussed later) were configured into the required circuits and the sensitivity of these sensors was noted to various magnets types. Both alnico 5 magnets indicated the triggering of sensors over much larger air-gap lengths compared to the ceramic types. Among the two alnico 5 magnets, the 6

mm bar magnet was found magnetically superior and triggered the sensors at higher air-gaps than the 4 mm size . The air-gap lengths thus obtained with a 6 mm x 20 mm long alnico 5 magnet are given in Table 4.1.

4.4 TESTING OF SENSORS

The simplest form of a magnet which will operate any magnetic field sensor is a rod or bar (Anon. 1986). Wheelock (1981) has described two ways of moving a magnet relative to a sensor to achieve a useful relationship between the magnetic field strength and the distance between the magnet and the sensor (air gap). With either, the axis of the magnet is perpendicular to the plane of the sensor but the motion is in the axis of the magnet (head-on) in one case, whereas it is lateral to the axis (slide-by) in the other. Figure 4.1 illustrates the above mentioned motions.

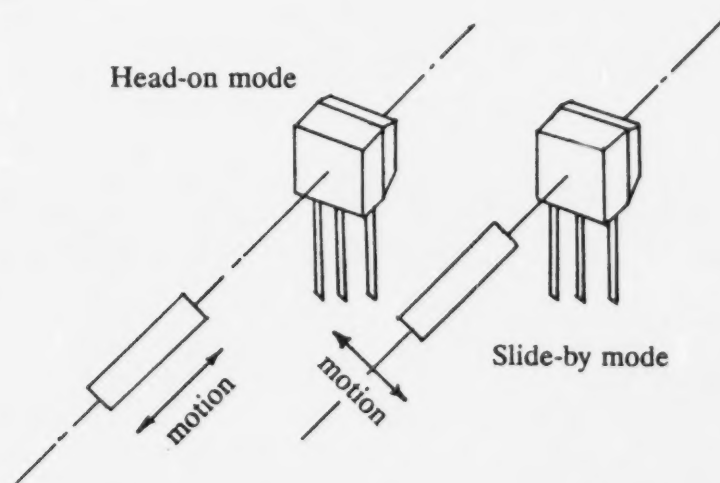


Figure 4.1 Head-on and slide-by position sensing (Adapted from Anon. 1986)

Some digital output sensors (bipolar) require the proximity of both poles of a magnet (south and north) in a sequence (Anon. 1986). For the application in question there is no assurance that both poles of the magnet will always pass close enough to the sensor. Thus the digital bipolar sensor was omitted. Analog bipolar

sensors, on the other hand, were included since they do not require proximity of both poles in sequence.

A bench test was deemed necessary to find a suitable sensor since manufacturers use a variety of magnets in calibrating their products. The previously selected, Alnico 5 magnet was used to measure the limiting air gap for all the sensors chosen for testing. Based on manufacturers' specifications the following sensors were tested:

- (1) **KMZ-10A** and **KMZ-10C** magneto-resistive types, from Phillips Electronics, and
- (2) **UGN-3019T** and **UGN-3030T** Hall-effect switches along with **UGN-3501U** Hall-effect linear sensor from Sprague Electrical.

The bench test was limited to using the magnet in the head-on mode position. For analog type sensors, the maximum air gap at which the sensors would detect variations in the changing magnetic flux was noted. For the digital switches, the air gap at which the magnet would trigger it on and off (operate and release) was noted. The maximum air gaps obtained in bench testing of these sensors are tabulated in Table 4.1.

Table 4.1 Maximum air gaps for some digital and analog magnetic-field sensors with a 6 x 20 mm bar magnet (Alnico 5).

Type	Model	State	Air gap
Digital	UGN-3019T	Operate	3 mm
		Release	5 mm
	UGN-3030T	Operate	7 mm
		Release	9 mm
Analog	UGN-3501	—	10 mm
	KMZ-10A	—	70 mm
	KMZ-10C	—	35 mm

The air gaps for triggering the UGN-3019T sensor on and off are 3 and 5 mm. According to the manufacturer (Anon. 1987) the operate/release (on/off) happens at magnetic field strengths of approximately 420 and 320 gauss respectively. The air gaps for the UGN-3030T were 7 and 9 mm. In case of UGN-3501U analog sensor, no measurable change in output voltage was observed for an air gap greater than 10 mm.

Figure 4.2 shows the air gaps obtained in the testing of UGN-3019T and 3030T sensors and the Figure 4.3 corresponds to the testing of UGN-3501U sensor.

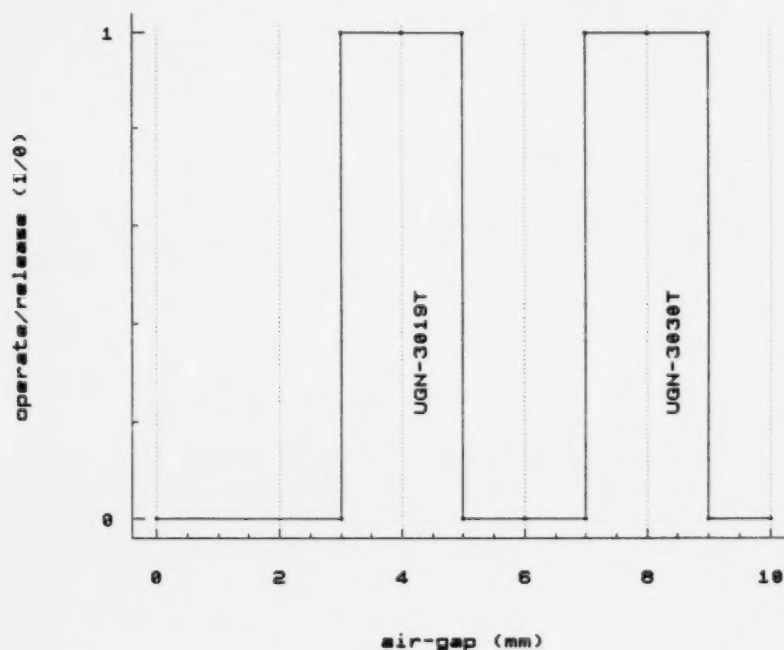


Figure 4.2 Sensor on/off versus air gap for UGN-3019T & 3030T

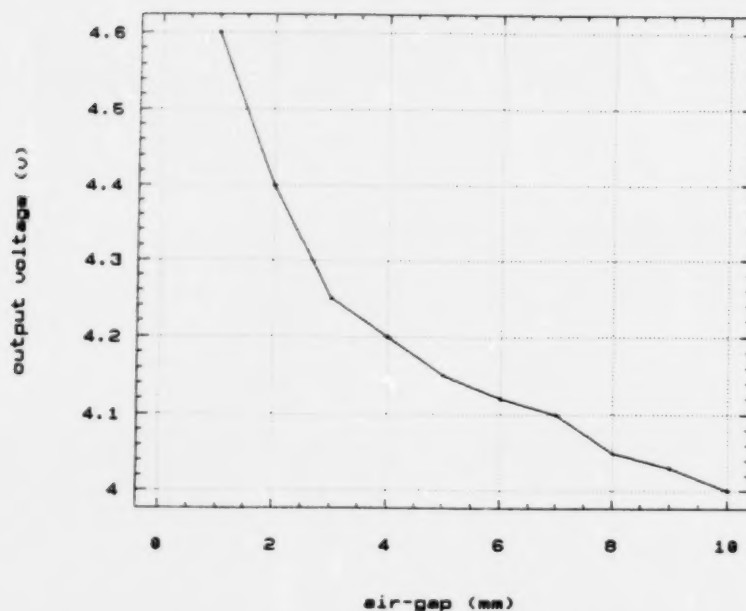


Figure 4.3 Sensitivity versus air gap for UGN-3501U sensor

Figure 4.4 is the output voltage versus air-gap lengths obtained for the KMZ-10A sensor. The KMZ-10A and 10C were highly sensitive to the magnetic field. The maximum air gaps were respectively 70 and 35 mm. Furthermore, the magnet could be sensed in orientations other than the head-on mode but the gaps were much less, and the minimum air gaps obtained were around 20 mm for the 10A and 15 mm for the 10C. When in range, the output voltage for both sensors varied in direct proportion to the air gap.

The KMZ-10A sensor was chosen because of the need for a sensor to detect a magnet at a large air gap even though it was more than double the cost of the UGN types. It was only slightly more expensive than the KMZ-10C sensor. The mechanical and electrical characteristics of the KMZ-10A sensor are given in Appendix E.

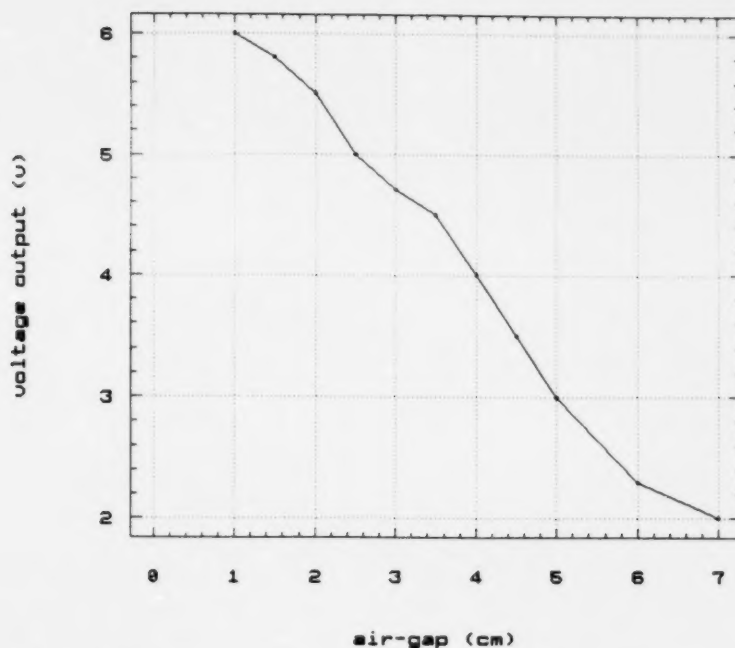


Figure 4.4 Output voltage versus air-gap lengths for KMZ-10A sensor

4.5 MOUNTING THE SENSORS

The sensitivity of the KMZ-10A sensor and the length of each concave section permitted a total of 32 sensors per concave section (16 on each end) of the IH 1460 combine at a spacing of 20 mm. Thus, a total of 96 sensors in two rows were required for the three concave sections. Figure 4.5 shows the various dimensions of an acrylic strip before mounting.

The sensors were glued into pockets which had been milled in acrylic strips (Plate 4.1). After gluing, other milled strips were cemented to this strip thus minimizing the risk of damage by completely encasing the sensors. The strips were fastened to the concave with bolts adjacent to the entry and exit of the concaves. Plate 4.2 shows the mounting of the sensors strips on the concave.

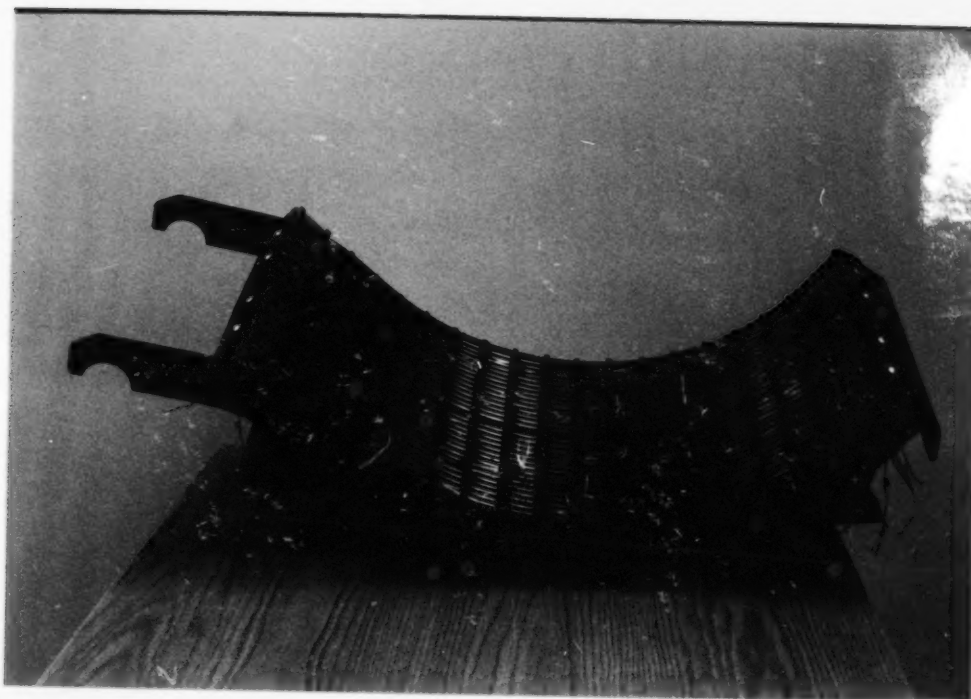


Plate 4.2 Sensor strips fastened to the concave sections

4.6 INTERFACING CIRCUITS

The signals of the Hall-effect and the magneto-resistive sensors require amplification and conditioning for use with a data acquisition system. Though the essential circuits are given by Anon. (1987 & 1988), some experimentation was necessary with the latter because the magnitude of resistors was not specified. Figure 4.6 show the circuit diagram used for testing the UGN-3501U sensor whereas, Figure 4.7 show the diagram for UGN-3019T and UGN-3030T sensors.

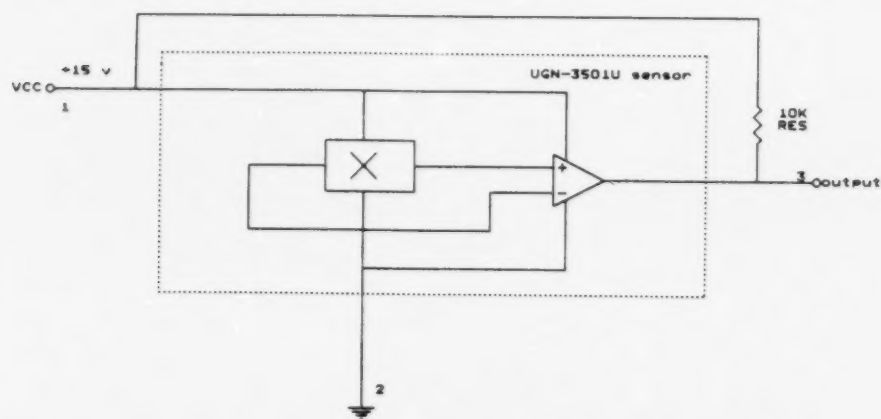


Figure 4.6 Circuit diagram for UGN-3501U sensor

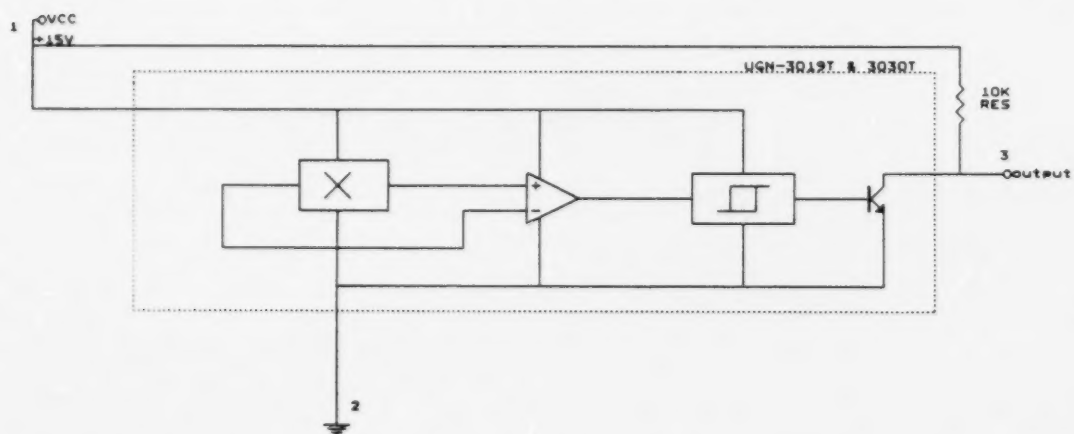


Figure 4.7 Circuit diagram for UGN-3019T and 3030T sensors

The Figure 4.8 shows the circuit diagram used for obtaining the magnetic field sensitivity versus the air-gap lengths for KMZ-10A sensor. A diode was added in the final output of the circuit to prevent a negative output.

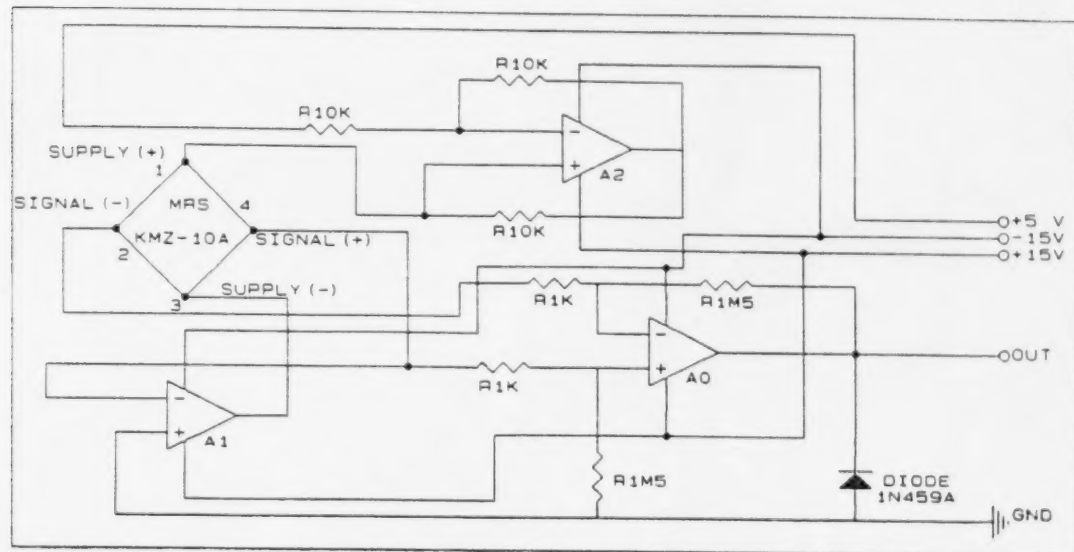


Figure 4.8 Circuit diagram for the KMZ-10A sensor

The output of the bridge (KMZ-10A), which indicates the degree of imbalance, is amplified by op-amp A0 and the common mode rejection is provided by a feedback network incorporating op-amp A1 (Anon. 1988).

The temperature coefficient of this bridge is not very high (typ. 0.25 %/K) (Appendix E) (Anon. 1988). Therefore, a negative-impedance converter circuit incorporating op-amp A2 was used which acts as a temperature dependent voltage source for the bridge (Anon. 1988). This set-up provides means for correcting any temperature variations using the bridge resistance as the controlling parameter. Any change in bridge resistance (caused by a change in operating temperature) will effect the voltage across the bridge. According to Anon. (1988), the output signal of A2 then acts to restore this voltage to it's original value (+5 V). A0, A1

and A2 are part of the same microchip; LM324. A power supply, model HP 6255A (dual DC power supply), was employed for interfacing all the 96 sensor circuits.

The final output of this circuit was modified to result in a spike of +2 and higher depending on the proximity of the magnet. The value of 2 V was obtained at an air-gap length of 70 mm and was sufficient to register with the Data Acquisition System (DAS).

The final circuit was fabricated as a printed circuit board (PCB). This is desirable in cases where a large number of repetitions are needed (96 in this case). Each sensor required it's own circuit and 8 of them were etched on the same piece of the PCB (Plate 4.3).

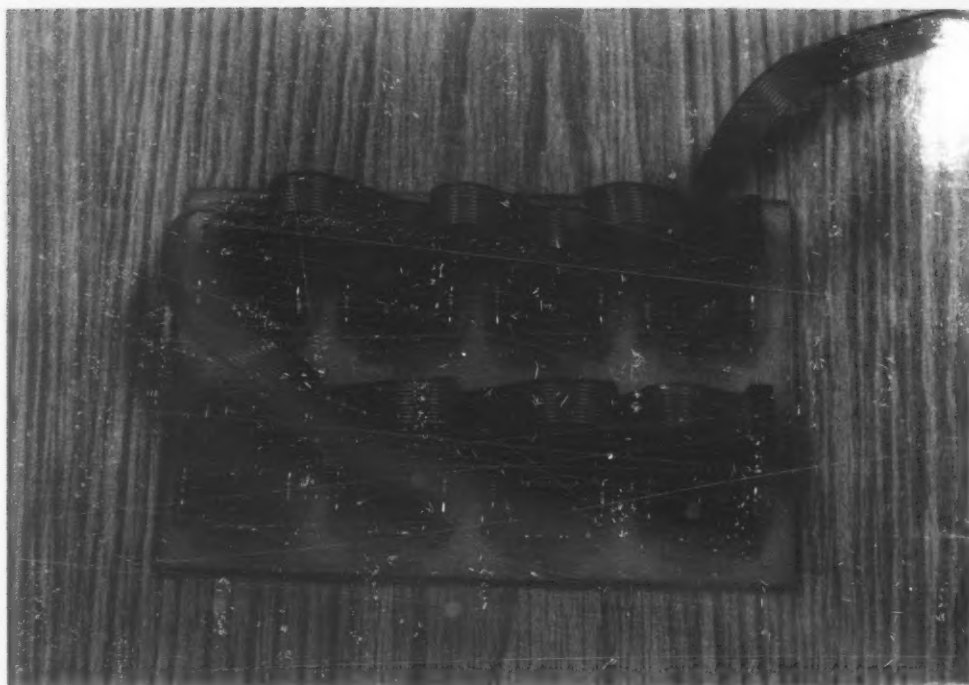


Plate 4.3 A group of 8 sensor circuits etched on a PCB

5. DATA ACQUISITION SYSTEM (DAS)

5.1 INTRODUCTION

A Data Acquisition System was designed and fabricated to be interfaced with the 96 magneto-resistive sensor circuits. The data acquisition system is an assortment of devices or components which can obtain data from sensors. The design was based on supplying the number or address, in a 7-bit binary code, of a sensor whose output was raised to +2 volts or more due to the proximity of a magnet. The system can be inexpensive if the functions are limited and a dedicated design is utilized. Consequently a single chip micro-computer (Motorola M68HC11A8) evaluation board (aka Buffalo board) programmed to operate in the interrupt mode was chosen. With modifications, the system was capable of acquiring up to 256 addresses.

The M68HC11A8 evaluation board is a versatile single-chip microcomputer with the capability of both analog and digital processing. It has an A-D converter on board along with a serial communication port for downloading the software and uploading the data etc. The provision for two control ports used either as input or output alongwith the ports provided exclusively for inputs and outputs makes it immensely useful in places of multiple tasking. The timer system and a pulse accumulator is also part of the microcomputer used for recording the elapsed time in clock cycles at the operating frequency.

A block diagram of the instrumentation is given in Figure 5.1 with a complete circuit diagram of the data acquisition system in Figure 5.2a and Figure 5.2b.

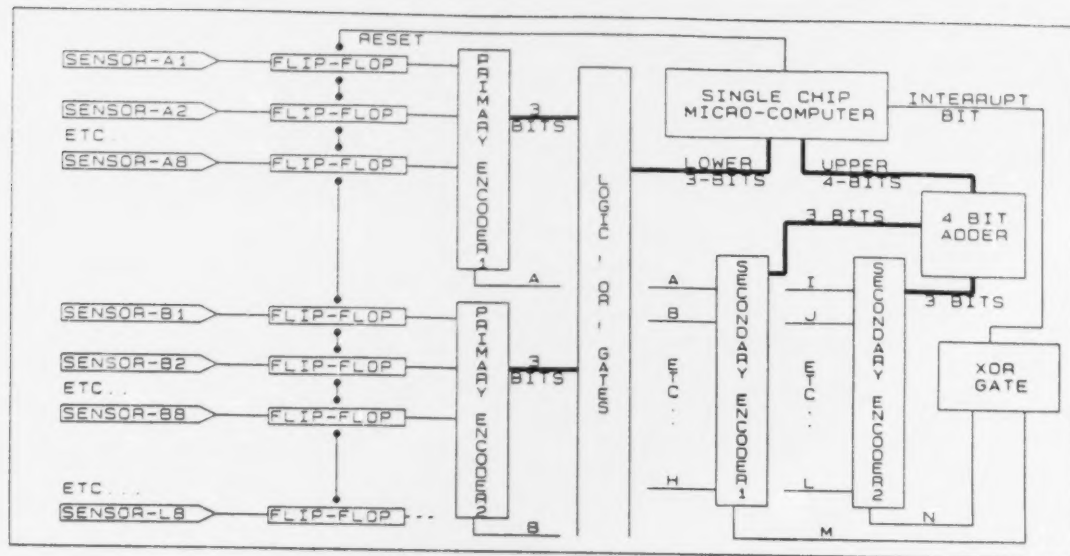


Figure 5.1 A block diagram of the instrumentation to measure the material flow.

5.2 SYSTEM COMPONENTS

The principle components of the DAS consist of a Dual J-K flip flop, an 8-bit priority encoder and a 4-bit full adder along with the logic devices also known as gates.

A Dual J-K flip flop (74HC107) is a digital circuit whose output signal depends not only on the input signal but also on a check signal applied previously to the input. One characteristic property is that the output state does not change when the input signal disappears but remains the same until the next input signal (RESET in our case) switches it to the other state (Wobschall, 1987). The input here is the output from the sensor's circuit and the feedback is the reset (+5 V) supplied by the microcomputer.

The primary function of an 8-bit Priority Encoder (MC14532B) is to output a binary address for the active input with the highest priority (Anon. 1989b). At the second stage of the DAS, the priority encoders with eight-bit data input (output from the J-K flip flops) along with enable input (+5 V) result in a 3 bit address output and a group select (GS) output. The truth table indicates (Appendix H) that, various input levels result in a specific output.

The 4-bit full adder (MC14008) is useful in binary addition of addresses and other arithmetic applications (Anon. 1989b).

A complete list of the parts and their quantities is given in Appendix G. Also important is a capacitor ($0.01\ \mu\text{F}$) for each microchip to *ground* any AC transients present in the power supply.

5.3 OPERATION DESCRIPTION

5.3.1 Data Acquisition System

The flip-flops (Motorola 74HC107) are used to register or latch the voltage spike (+2 Volts or more) from a sensor and maintain an output +5 V until reset to 0 V by a reset pulse (Wobschall 1987) from the microcomputer board. With a latched output the primary encoders (Motorola MC14532B) respond with a three bit binary number (address) defined by either high or low voltage at three output pins. If two or more flip-flops are latched within each block of eight, then the primary encoder selects only the highest address as the active output (Anon. 1989b). This will cause an unknown error in determining the exact position of the sensor but it is small as well as remote. The magnitude of the error is a function of the sensors spacing noted previously.

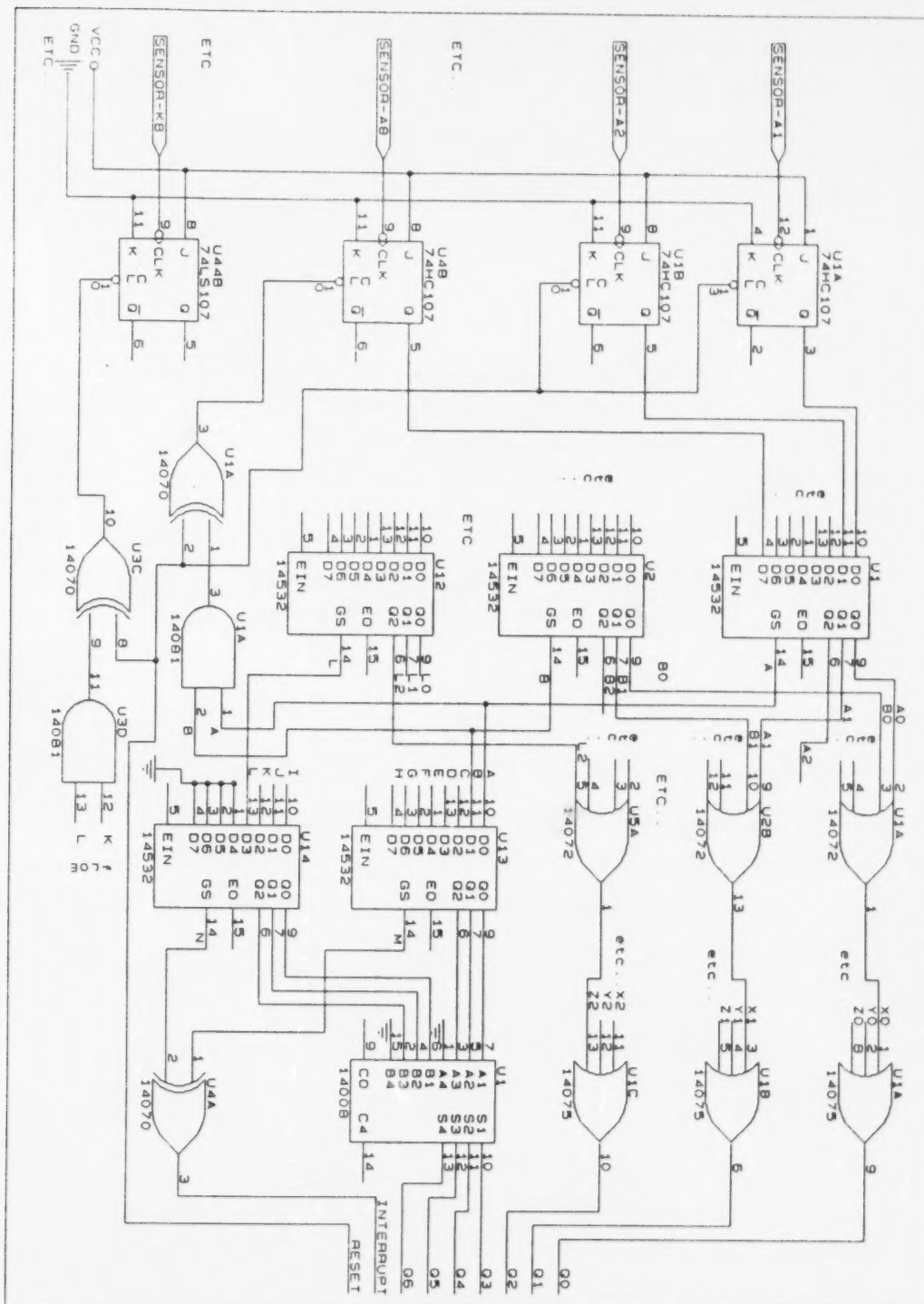


Figure 5.2a The circuit diagram of the dedicated data acquisition system

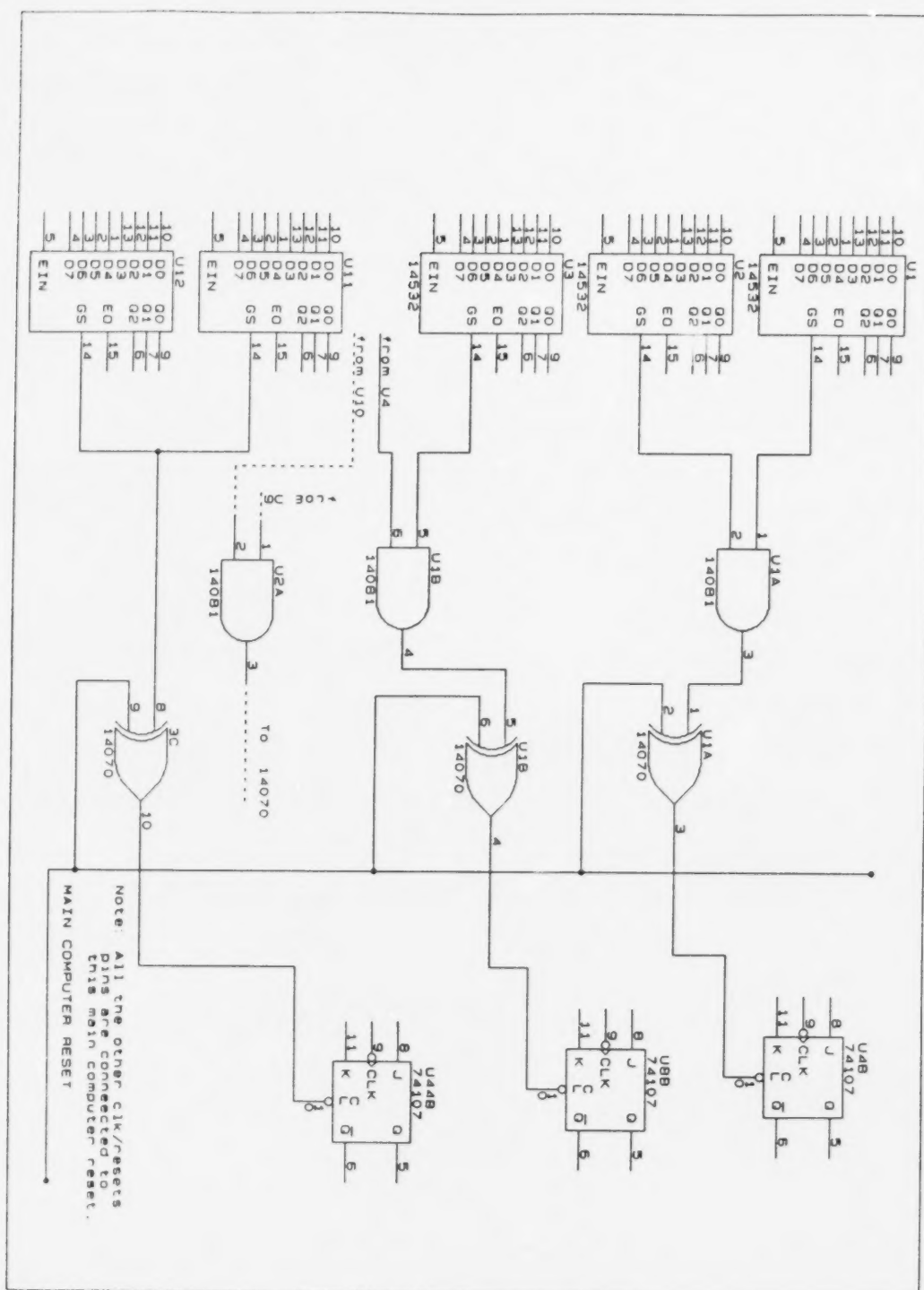


Figure 5.2b The arrangement of the main computer reset

The output of the logic OR gates is the three bit address that was generated by one of the 12 primary encoders at one time. The possibility of adjacent flip-flops in neighbouring blocks being latched at the same time is eliminated by an arrangement of gates to reset the lower numbered flip-flop to 0 V. This was necessary so that the sensor with the highest address would be recorded only. This is also the case when more than one sensor is triggered in a block of eight and DAS gives information only about the one with the highest address. The three bit address is the lower three bits of the seven bit binary address used by the microcomputer board. The Plate 5.1 shows the actual microcomputer board used for this purpose.

Each primary encoder has a group select (GS) output in addition to the address outputs. One of the 12 (A to L, Figure 5.2a) will be high when the address output is active. When high, one of two secondary encoders (Motorola MC14532B) will generate a three bit address corresponding to a specific level of primary encoder inputs. The two three bit address outputs from the two secondary encoders are added together by a four bit full adder (Motorola MC14008B) which outputs a four bit number. This four bit address (upper four bits) from the adder and the previously obtained three bit address output (lower three bits) from the OR gates constitute the total 7-bit number. Thus, a seven bit binary address for one of the 96 sensors is obtained and interfaced to the microcomputer board.

The secondary encoders, like the primary encoders, also have an output which will be high when the address output is active. Using an EXCLUSIVE OR (XOR) gate the output acts as an interrupt bit for the program which is resident in the RAM of the microcomputer board. Plate 5.2 shows the designed and assembled system ready for acquiring data.

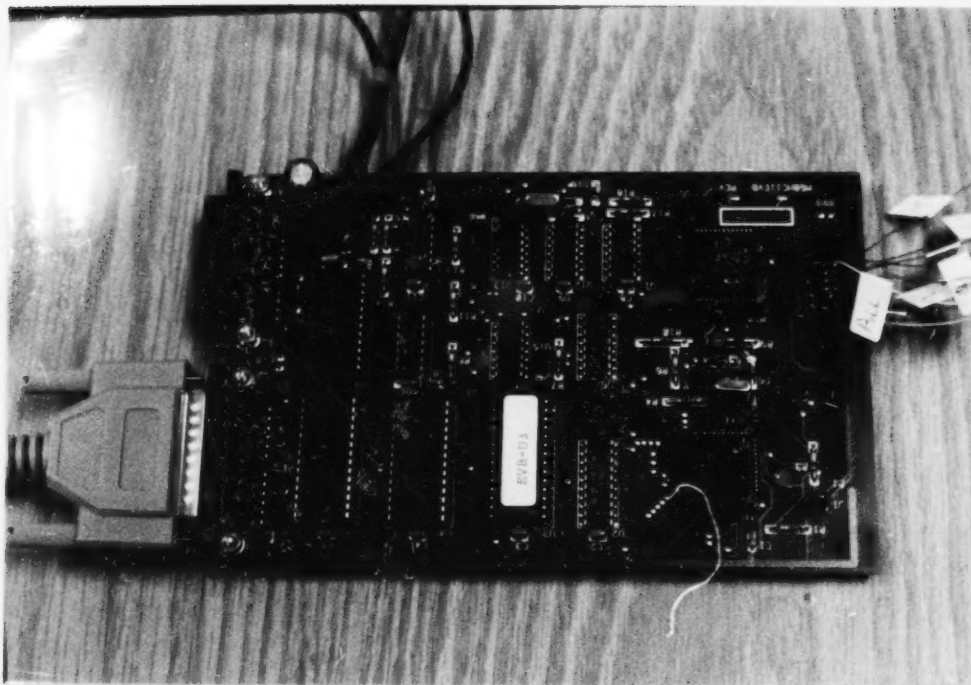


Plate 5.1 The Microcomputer board (MC68HC11-EVB)

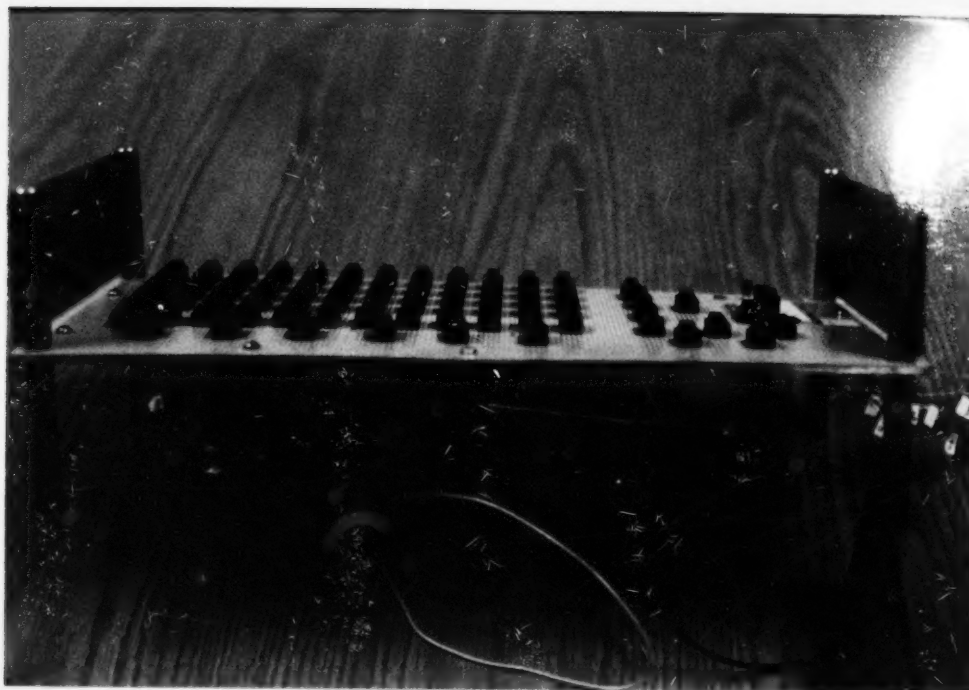


Plate 5.2 The assembled Data acquisition system board

The following is an example demonstrating the 7-bit binary output from the DAS for a known sensor triggered-on. When sensor number 4 is triggered-on due to the proximity of the magnet, the bistable device IC # 2 (74HC107) records a high input at the pin Clock 2. The resulting output is latched high ('1') at the pin Q2. In the next step, this output acting as an input to the primary encoder registers itself at the pin D3 (Appendix H). All the other input levels being low at this stage, the output is a three bit binary address (1 1 0) at the Q0, Q1 & Q2.

The additional output at pin GS, (A to L, Figure 5.2a) from this IC is also in high state. This (1 1 0) address output is an input to the logic OR gates (MC14072B) in the next stage and responds with a lower 3-bit address of the final 7-bit address for the sensor number 4 triggered-on. The GS output (high '1') from the primary encoder is an input to the secondary set of encoders (pin D0) and the resulting output is (0 0 0) at the pins A1, A2 & A3 prior to the addition by a 4-bit full adder (Motorola MC14532) (Appendix H). The other 3-bit address (B1 B2 B3) for the adder is obtained from the other secondary encoder and is (0 0 0). The resultant output (S1 S2 S3 S4) from this adder represents the upper four bit address for the final 7-bit number.

The additional output (pin GS) is high '1' at the secondary encoder (M, Figure 5.2a) and is low '0' for the next encoder (N, Figure 5.2a). The combination of these two outputs helps in constructing the interrupt bit for the programme. The interrupt bit in state high '1' signals the presence of data at the 7-bit address.

The final output combining the above 3 and 4 bit addresses can now be expressed as '00000011'. The meaning of this binary coded number in decimal form, is number 3. With sensor number 1 written in binary number as '0000000', the number 3 represents that sensor number 4 is recorded as triggered-on and the interrupt bit in high state. The Plate 5.3 shows the computer and DAS inside the plastic housing to minimize dust contamination.

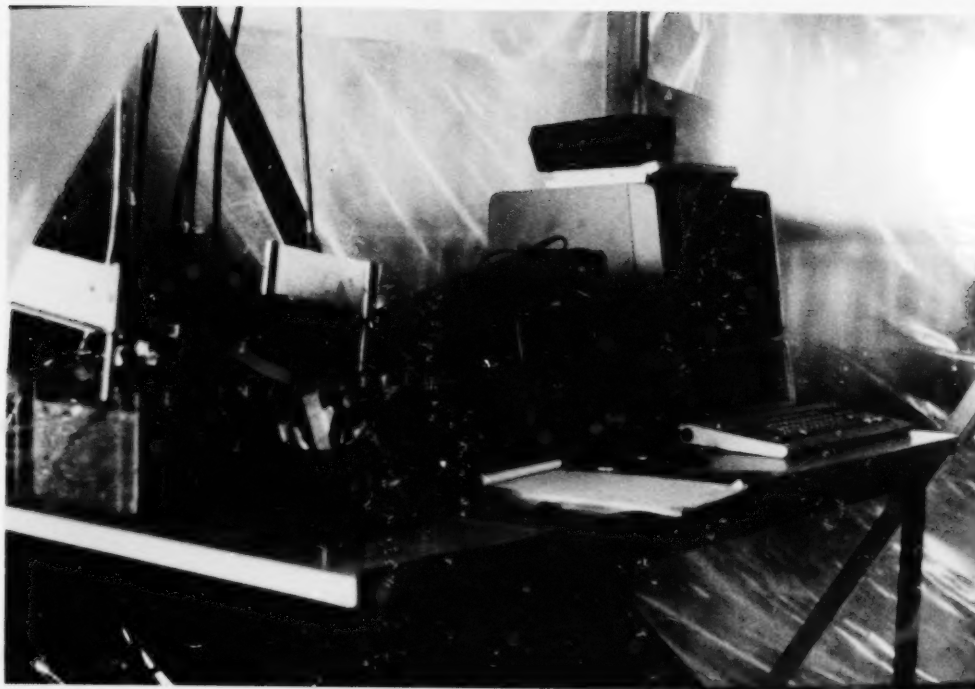


Plate 5.3 Experimental set up of the electronics with a PC inside the plastic housing

5.3.2 Software description

The RAM of the microcomputer board is accessed by a PC to down load the software (assembly language) and to up load the data. The software (Appendix C) is first converted into the machine code using AS11 assembler programme (Motorola Ltd. AZ, USA) and the machine code is then down loaded to the microcomputer RAM using ProComm communication software (DataStorm Technologies Inc. Columbia, MO). A listing of the program is given in the Appendix C with the flow chart given by Figure 5.3.

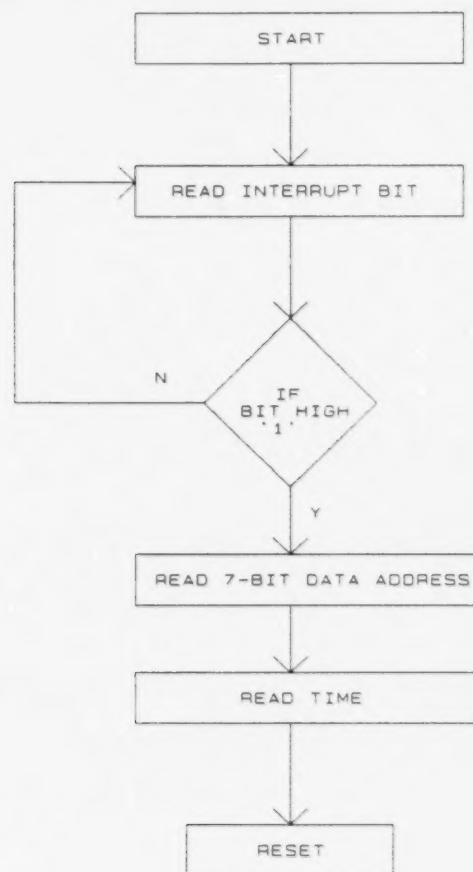


Figure 5.3 Programme flow chart.

The programme at the beginning is bypassing any read and record instructions and simply waits for the interrupt bit to be high (1). The interrupt bit will be high only when any one of the sensors is triggered high. With an interrupt bit in high state, the programme accesses the seven bit address at the input port of the microcomputer board (output from the DAS) and records it along with the time from the timer system in clock cycles as a 5-byte hexadecimal number. The first byte is the sensor address whereas the other four is the elapsed time in clock units. Once that data point is logged in, the microcomputer board sends a check (RESET) pulse to the DAS and sets it in the receiving mode.

The data must be up loaded from the microcomputer board and saved by the PC after each run because the data in the RAM is cleared prior to each usage. This is necessary because of the limited memory of the microcomputer board.

The sampling rate required for a rotor speed of 1000 rpm and two rows of sensors is about 25 msec. With the microcomputer board operating at 2 MHz, the sampling rate of the DAS was determined from the total number of programme instructions and the clock pulses required for execution of each instruction. The sampling rate of the board is therefore noted to be approximately 125 μ sec which is about 200 times faster than the rate needed to sample the data. This assures that all data will be logged in for the triggered sensors.

6. EXPERIMENT DESIGN and PROCEDURE

6.1 EXPERIMENTAL SET-UP

The experimental apparatus consisted of a rotor (610 mm diameter), cage and concave (less the discharge beater) from the rotary combine, along with the magnetic sensors and the Data Acquisition System (DAS). The combine components were from 1978 model 1460 International Harvester. The rotor and assemblies were mounted into a steel structure totally enclosed in plywood. The equipment, along with a twin set of draper conveyors (15 m long x 0.9 m wide), is part of the laboratory facilities at the Ellerslie Research Station of the University of Alberta.

The equipment set up has been described previously by Harrison (1991). The rotor assembly was driven by the Power Take-off (PTO) of the CASE IH model 7130 tractor. The conveyer belt was driven by a three phase, 3.7 kW asynchronous motor. The conveying speed was 1.0 m/s.

6.2 EXPERIMENTAL DESIGN

The transport vanes inside the rotor housing were mounted such that their position could be altered to give three levels of vane angles; namely, 11°, 22° and 33°. Therefore, observations led to the design of a block experiment with three vane angles; namely, 11°, 22° and 33° and two levels of rotor speed; 800 and 1000 RPM to be replicated three times. A constant material feed rate of 10 t/h and a concave clearance of 7 mm were adopted for the experiment. The amount of material to be placed over the conveyer belt was calculated based on the conveying speed and a 10 t/h feed rate. The Figure 6.1 is schematic of the experimental apparatus.

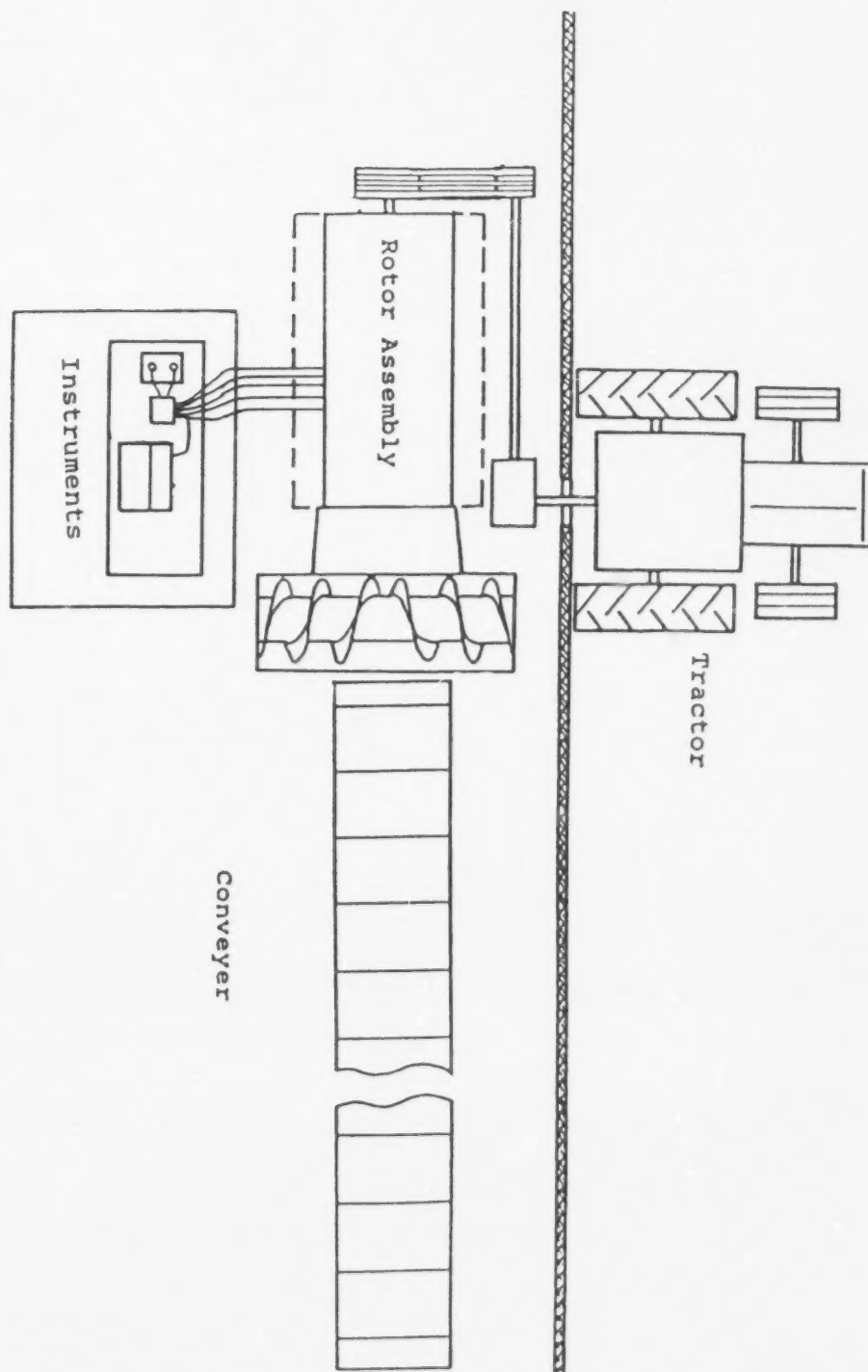


Figure 6.1 Threshing test equipment (Adapted from Liu, 1990)

For one level of a vane angle, the two rotor speeds were used at random for three replicates before changing to the next vane angle. For statistical analysis, the three vane angles constitute three blocks of experiments. The rotor speed has an interaction with the vane angle within each block. In this experiment design, the interaction of rotor speed and replication nested in the vane angle defines the experimental error term.

6.3 EXPERIMENTAL PROCEDURE

With all the experimental units in place, the crop bundles (Spring Wheat at 14 % m.c. wet basis) were taken from a stack of crop, weighed on a platform balance and evenly distributed onto the conveyer belt. According to Hall et al. (1985), Gasparetto (1989), Skromme (1977) and Wacker (1985), the residence time of material from input to output (including threshing) in a rotary combine is only about 3 seconds. The material quantity on the conveyer belt was sufficient for a 10 second run and the magnet was placed at the centre of the material length. This was necessary to assure full flow of the material before and after the magnet's travel.

The rotor speed was adjusted according to a hand-held contact tachometer. When the rotor speed was observed to be within ± 3 rpm of the desired value in the unloaded condition, the conveyer belt was started. As soon as the material entered the combine, the data acquisition system (DAS) was activated. When the material stopped appearing at the discharge end, the DAS was deactivated.

A few initial runs were carried out without the magnets to check the system for any spurious signals from rotating metal elements and any other circuit interfacings. With the rotor operating at the desired speeds, inappropriate triggering of a few sensors was noted. Problems found were due to loose and faulty connections.

The next few runs were carried out to determine how many magnets in a group along with their orientation would yield a large number of data points. One or two magnets occasionally triggered a few sensors but often they would not trigger any at all. It was also found impossible to recover these magnets and ascertain their condition. A group of four individually centred magnets in the plastic (heat shrink) tubings (Plate 6.1) with their opposite poles facing each other was found to be optimum. In some cases for such a group, one or two magnets were found crushed in the process, but the remaining number was still sufficient in yielding some useful data. A greater than four number of magnets in a group resulted in a larger destruction of the expensive magnet and the tubes containing them. Hall et al. (1982) did not report on the final condition of the magnets that they used.

Fragility of the electrical connections required they be tested between each block of experiment for any spurious signals. Once again, with the rotor operating at the desired speeds, the inappropriate triggering of a sensor was noted and corrected.

A total of 18 runs were conducted to fulfil the requirements of the factorial experiment. The data for each run was stored on the microcomputer board and then down-loaded to a computer diskette before the next run. This was essential because of the limited memory of the microcomputer board.

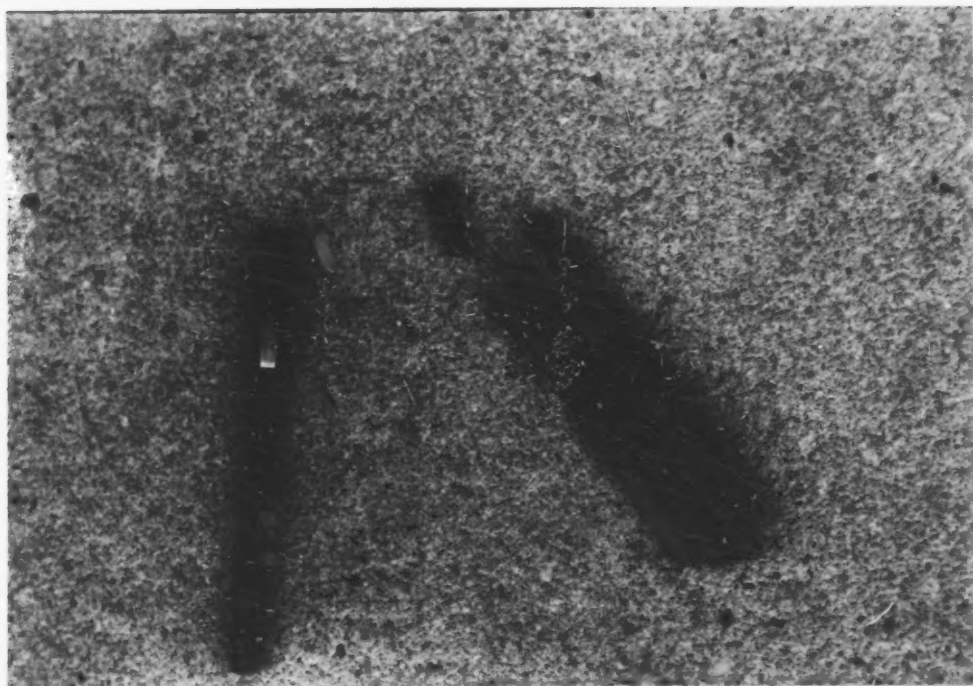


Plate 6.1 The magnet and the heat shrink tube prior to embedding in the crop material.

6.4 DATA ACQUISITION

It has been previously established that the sampling rate of the DAS is almost two hundred times faster than the sampling rate required for a rotor speed of 1000 rpm and two rows of sensors. This allowed for logging in of all those sensors that were triggered and also in some cases caused the appearance of the same sensor address at the next several intervals of time. This process is attributed to the fact that the magnet is moving past a sensor at a speed much less than the data acquisition rate. Hence, the DAS continues to record the same sensor until the magnet has moved out of the sensor's range. In processing, only the first data point of every sensor trigger-on was used. The raw data is given in Appendix I.

6.5 DATA PROCESSING

All the raw data in the hexadecimal form (Appendix I) was converted into the decimal form by hand. Another option would have been to write a programme to convert the hexadecimal numbers to decimal form. The sensor's status was registered along with the sensor's position. The time in clock units was converted to the real time at which a sensor was observed to be triggered high ('1').

The following example illustrates how the raw data was changed into decimal form. A 5-byte data value of 09 00 B5 9F E0 is taken for a run where rotor rpm was set at 800 and vane angle of 11° for first replicate as given in Appendix I. The 09 refers to the sensor address that was triggered high and the decimal form of hex 09 is 09. However, the DAS in its binary output form refers to 09 as the 10th sensor. The next four-bytes number when changed to decimal number is expressed as 11902944. These are the number of clock cycles that the board registered in its timer system before the sensors number 10 was triggered high and sensed by the DAS. The operating frequency of board being at 2 MHz, the number 11902944 when expressed in real clock time is 5.951 s. The data thus

converted reads that the sensor number 10 was triggered at 5.951 s. This sensor number 10 is located at an axial distance of 0.14 m from the beginning of threshing concaves. All the data is converted using the same procedure and is given in Appendix A.

The axial distance between two successive sensors has been established previously (20 mm) and the arc of the concave grates (720 mm) was measured as was the arc of the rotor housing (vane traverse) (1550 mm). For the time it takes for the magnets to travel from one sensor to the other, the axial and tangential velocities of the magnets for both the concave and transport vane traverses can be calculated. The axial velocities are thus given as follows:

$$V_{ax} = d_{ax} / t_s \text{ where;} \quad (6.1)$$

V_{ax} is the axial velocity,

d_{ax} is the axial distance between the two consecutive triggered sensors and,

t_s is the time interval in seconds for the magnet to travel between these two. If the time (t_s) is noted to be for the concave traverse, the velocities in concave traverse are obtained. If the time for the magnet travel is for the vane traverse, the velocities in vane traverse are obtained.

The tangential velocities are given as follows:

Tangential velocity (mm/s) in the concave traverse is equal to 720 mm divided by the time (t_s).

Tangential velocity (mm/s) in the vane traverse is equal to 1550 mm divided by the time (t_s).

7. DISCUSSION OF RESULTS

The data were plotted in three dimensions to aid in identifying the sensors which had been triggered by the magnets (Figures 7.1 to 7.18). Because the figures are viewed from the rear they comply with the orientation normally used for right and left-hand direction. The rotor turns clockwise when viewed from the rear; thus, some of the crop enters the concave on the right or far side.

A consequence of the foregoing was the adoption of an identifying sequence of triggered sensors. It required that the first triggered sensor on the right or entrance side of the concave be identified as "A", whereas the first triggered sensor on the left side be identified as "B". With the sequence "A" to "B" a traverse of the concave is indicated.

It can be seen in Figures 7.9, 7.10, 7.15, 7.17 and 7.18 that the "A" sensors were absent thus indicating that either the magnets failed to trigger a sensor or they entered along the front edge of the concave between the right and left side. In Figures 7.2, 7.7 and 7.14 it was the "B" sensors that were absent. Because there was an "A" sensor it was presumed for these instances that the magnets failed to trigger the "B" sensors.

If it appeared that the magnets made or started to make another traverse of the concave then the second triggered sensor on the right side was identified as "C" with the second on the left side, if it occurred, as "D" (Figures 7.1, 7.4, 7.7, 7.8, 7.9, 7.10, 7.15, 7.17 and 7.18). With the sequence "B" to "C" a traverse of the transport vanes in the rotor cover is indicated whereas with the sequence "C" to "D" another traverse of the concave is indicated. Some triggered sensors were left unidentified (Figures 7.1, 7.9, 7.10, 7.15 and 7.18) because it was unclear what was the prior triggered sensor.

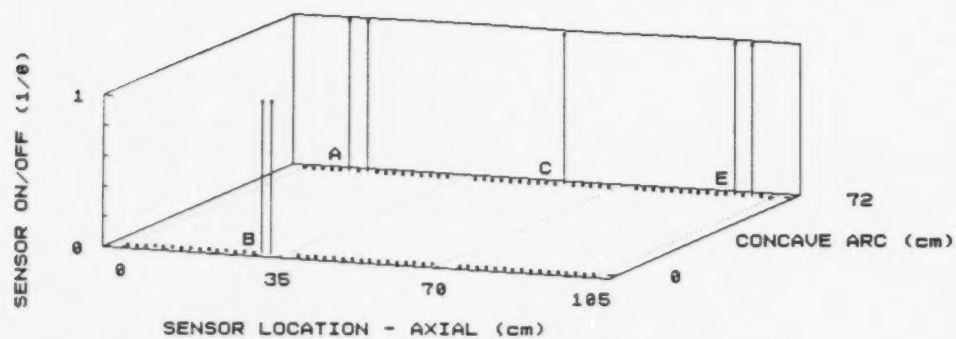


Figure 7.1 Triggered sensors for a rotor speed of 800 rpm, vane angle 11 deg., replicate 1

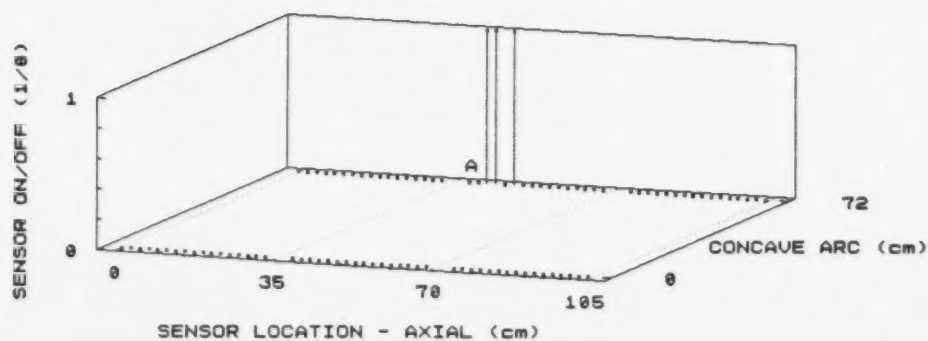


Figure 7.2 Triggered sensors for a rotor speed of 800 rpm, vane angle 11 deg., replicate 2.

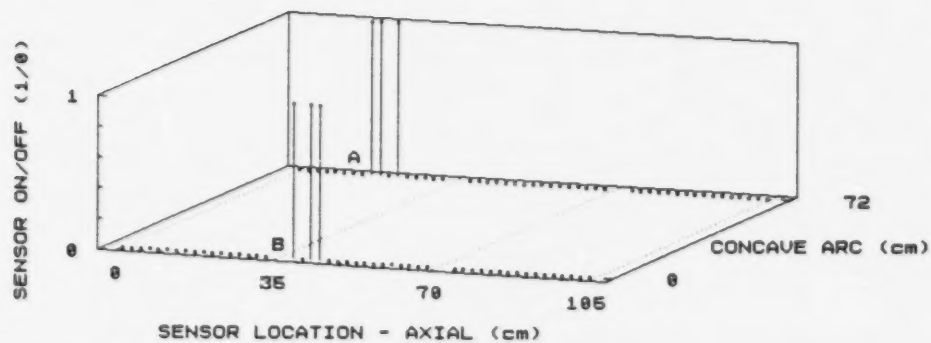


Figure 7.3 Triggered sensors for a rotor speed of 800 rpm, vane angle 11 deg., replicate 3.

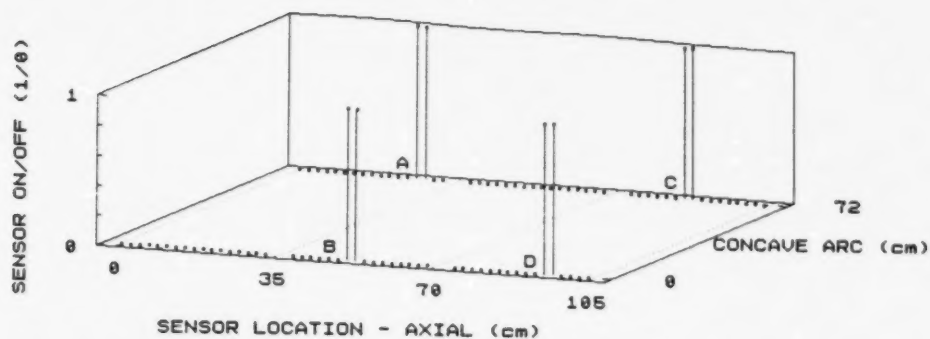


Figure 7.4 Triggered sensors for a rotor speed of 800 rpm, vane angle 22 deg., replicate 1.

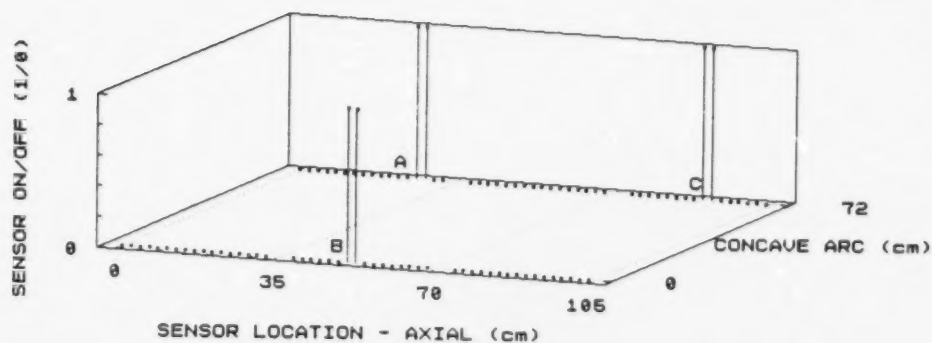


Figure 7.5 Triggered sensors for a rotor speed of 1000 rpm, vane angle 22 deg., replicate 2.

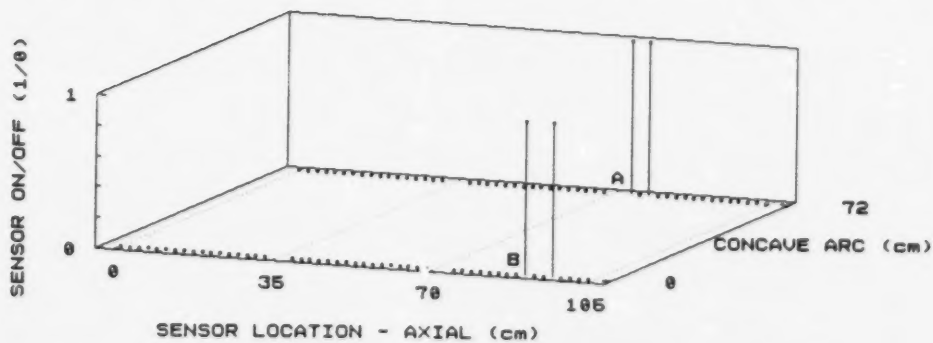


Figure 7.6 Triggered sensors for a rotor speed of 800 rpm, vane angle 22 deg., replicate 3.

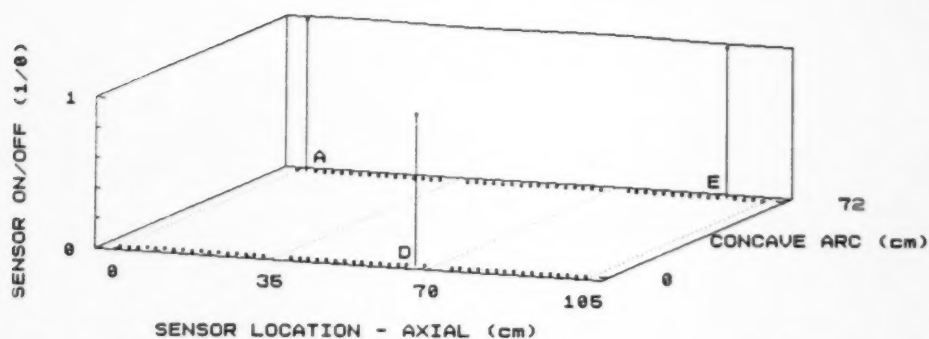


Figure 7.7 Triggered sensors for a rotor speed of 800 rpm, vane angle 33 deg., replicate 1.

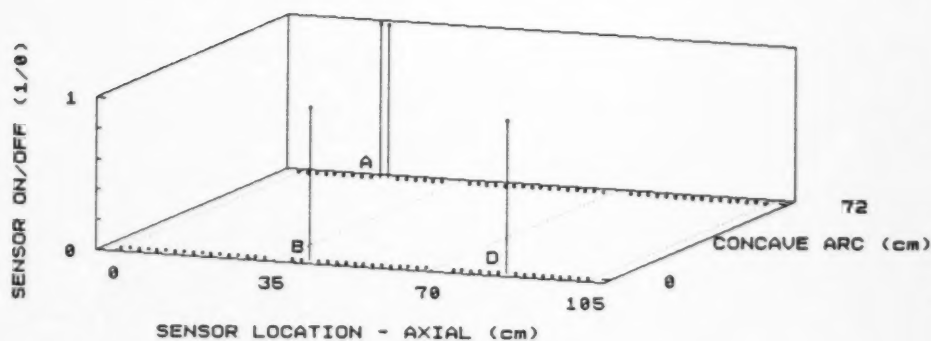


Figure 7.8 Triggered sensors for a rotor speed of 800 rpm, vane angle 33 deg., replicate 2.

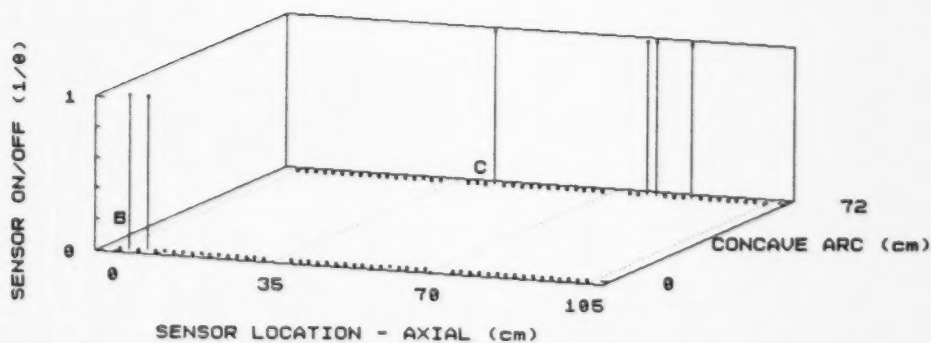


Figure 7.9 Triggered sensors for a rotor speed of 800 rpm, vane angle 33 deg., replicate 3.

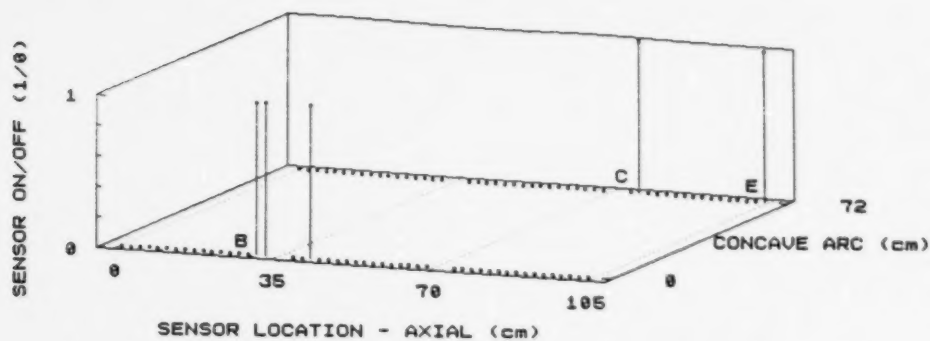


Figure 7.10 Triggered sensors for a rotor speed of 1000 rpm, vane angle 11 deg., replicate 1

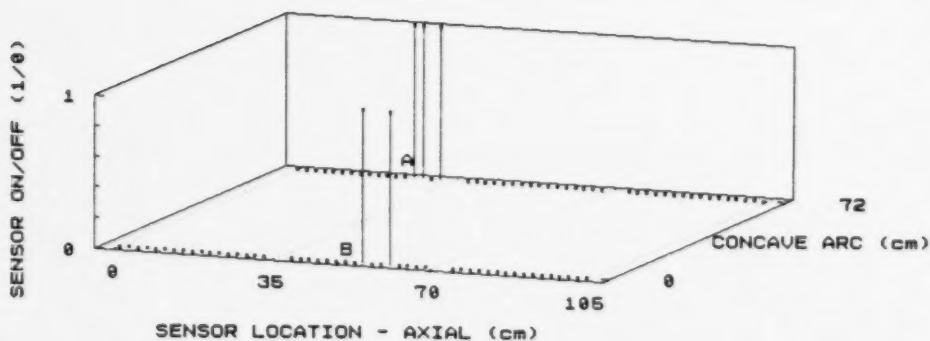


Figure 7.11 Triggered sensors for a rotor speed of 1000 rpm vane angle 11 deg., replicate 2.

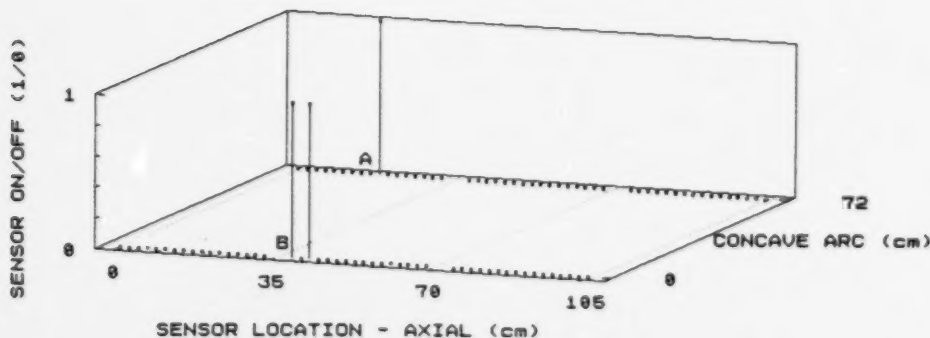


Figure 7.12 Triggered sensors for a rotor speed of 1000 rpm, vane angle 11 deg., replicate 3.

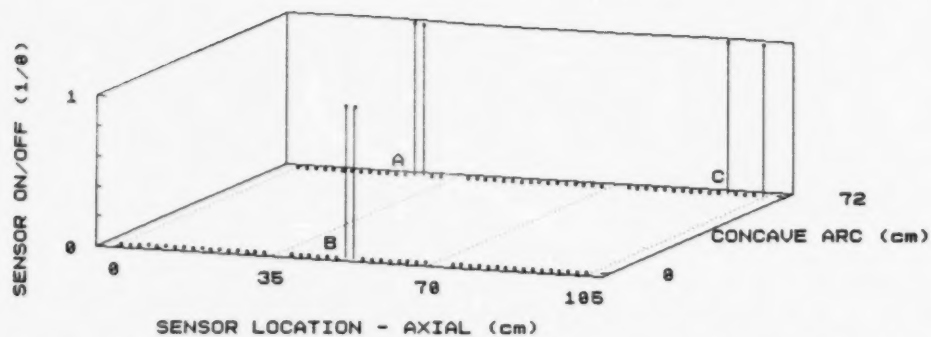


Figure 7.13 Triggered sensors for a rotor speed of 1000 rpm, vane angle 11 deg., replicate 1.

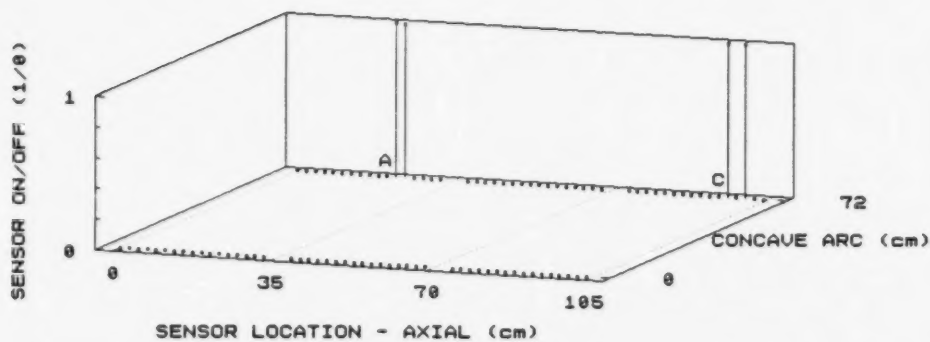


Figure 7.14 Triggered sensors for a rotor speed of 1000 rpm, vane angle 22 deg., replicate 2.

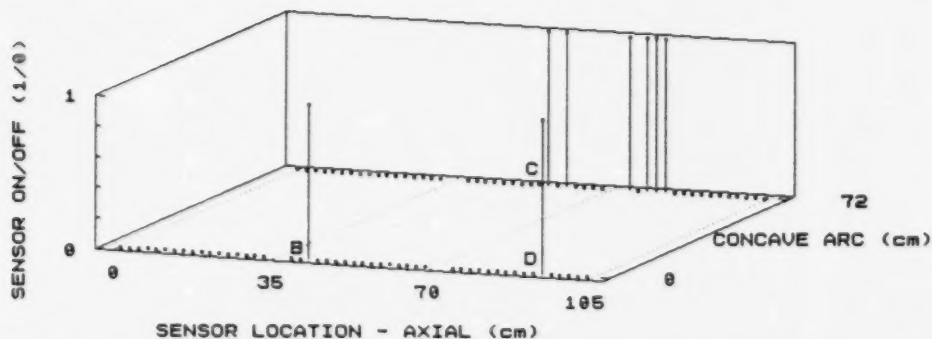


Figure 7.15 Triggered sensors for a rotor speed of 1000 rpm, vane angle 22 deg., replicate 3.

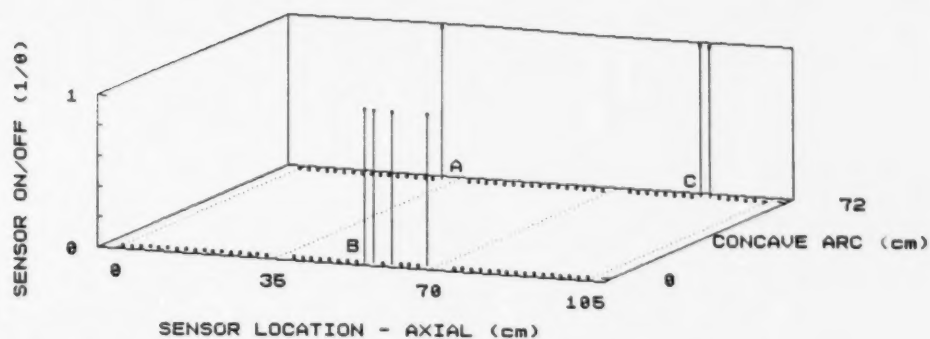


Figure 7.16 Triggered sensors for a rotor speed of 1000 rpm, vane angle 33 deg., replicate 1.

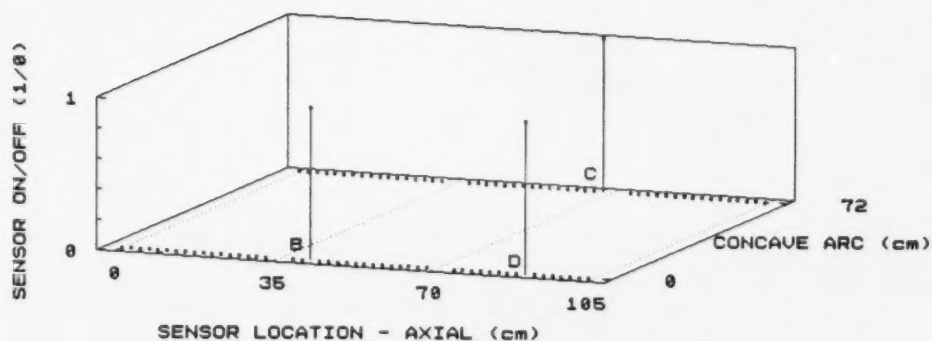


Figure 7.17 Triggered sensors for a rotor speed of 1000 rpm, vane angle 33 deg., replicate 2.

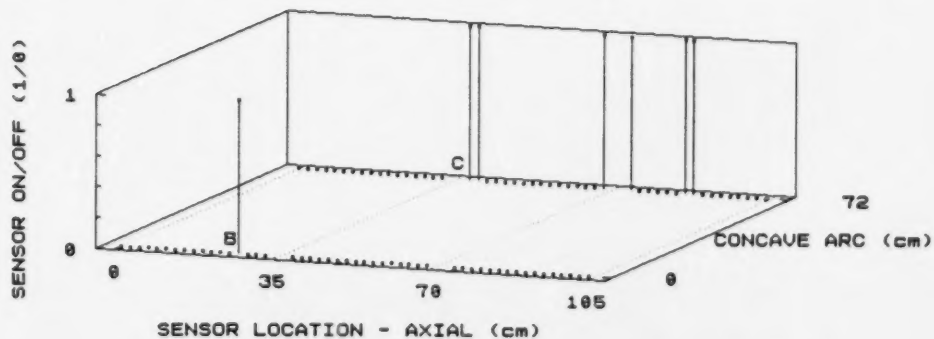


Figure 7.18 Triggered sensors for a rotor speed of 1000 rpm, vane angle 33 deg., replicate 3.

The absence of triggered sensors, such as Figure 7.2, made it impossible to define the axial displacement in a number of instances thus creating a situation of missing data. These instances are noted in Table 7.1. Neither an axial nor a tangential velocity can be calculated when only one sensor is triggered.

Table 7.1 Axial Displacements (cm) from Figures 7.1 to 7.18

Rotor speed (m/s)		CONCAVE TRAVERSE			VANE TRAVERSE		
		11°	22°	33°	11°	22°	33°
25	REP 1	16	20	72	26	34	32
	REP 2	—	28	22	—	38	—
	REP 3	14	18	—	—	—	48
32	REP 1	—	22	22	34	44	36
	REP 2	22	—	22	—	—	26
	REP 3	20	12	—	—	14	42

The missing data in Table 7.1 is not due to the sensors as they were always found to be intact and in working order. On the other hand the magnets were sometimes broken or crushed by the rotor or concave bars. Another explanation for the missing data is that the magnets were located between the rotor bars and not at the rotor periphery as they passed the sensor.

7.1 AXIAL and TANGENTIAL CROP VELOCITIES

The axial and tangential velocities of crop traversing the concave and vanes were calculated using the procedure noted previously from the data given in Appendix D. The mean velocities (see Table 7.4) are similar to those obtained by Kutzbach (1983) (see Table 2.2), Wacker (1985) and Gasparetto et al. (1989). The General Linear Model procedure in the Statistics Analysis System (SAS Institute Inc. Cary, NC USA) was employed for the analysis of variance because it can manage missing data. As can be seen in Tables 7.2 and 7.3 the analyses indicate that the

experimental factors of vane angle and rotor speed do not test significant even at 0.1 level of probability; i.e., the differences could have occurred by chance. This is attributed to the large random variations in the data, and to a lesser extent, the missing data. Kutzbach (1983) and Wacker (1985) used a similar method and obtained similar results.

Table 7.2 Analysis of Variance - Axial velocity at concave and vane traverses

Source of variation	Deg. of Freedom		Mean Square		F-Ratio	
	concave	vane	concave	vane	concave	vane
ANGLE	2	2	0.1508	0.1315	< 1	< 1
RPM	1	1	0.0198	0.1579	< 1	< 1
ANGLE*RPM	2	2	0.7764	0.0111	< 1	< 1
ERROR	7	5	1.1560	0.4455		

Table 7.3 Analysis of Variance - Tangential velocity at concave and vane traverses

Source of variation	Deg. of Freedom		Mean Square		F-Ratio	
	concave	vane	concave	vane	concave	vane
ANGLE	2	2	1.712	1.190	< 1	< 1
RPM	1	1	6.179	17.42	< 1	1.6
ANGLE*RPM	2	2	1.890	4.533	< 1	< 1
ERROR	7	5	9.486	10.88		

The variations in the velocities are largely attributed to uneven crop motion as the crop traversed the concave. According to Gasparetto et al. (1977) the motion is extremely irregular because the impacts by the moving rotor bars are interspersed with impacts by the stationary concave bars. Though the change in velocities may be small it is critical. For example Harrison (1989) concluded that the vanes affect the axial velocity because he found that the power requirements were affected. It follows that the technique may be unsuitable to discern the small but crucial differences in velocities caused by small changes in the vane angle and rotor speed.

Table 7.4 Mean axial and tangential velocities of the crop at concave and vane traverses.

Rotor speed (m/s)	Vane angle (degrees)	Axial (m/s)		Tangential (m/s)	
		Concave	Vane	Concave	Vane
25	11	1.0	1.3	4.8	8.0
	22	2.1	1.4	6.2	6.1
	33	1.7	1.5	3.7	6.0
32	11	1.9	1.6	6.6	7.2
	22	1.3	1.6	6.3	10.6
	33	1.9	1.9	6.3	8.3
Grand mean		1.7	1.6	5.7	7.7

The grand mean of the velocities are given in Table 7.4. As can be seen there is little or no difference between the axial velocities for the two traverses whereas the tangential velocity for the vane traverse is about one third larger than for the concave traverse. The axial velocities suggest that the vanes have no effect on the velocities; however, the difference must be obscured by random variations noted above. As for the tangential velocity it appears that the vanes do not retard the crop as much as the concave bars. This seems reasonable given that the concave bars are at right angles to the tangential movement of the crop whereas the vanes are not.

Crop flow angles with respect to the rotor axis were calculated from the means of the velocities in Table 7.4. For the concave traverse it is 73° and for the vane traverse it is 78° . The angles are some function of the helix angle of the rotor bars and friction, and to some extent, the helix angle of the vanes. Without slippage, for example, the flow angle would be 90° .

The average number of times that the crop traverses the threshing concaves for the two rotor speeds of 800 and 1000 rpm was respectively, 0.85 and 1.1. They

were obtained using an axial velocity of 1.65 m/s, the average of the two grand means given in Table 7.4, and the two rotor speeds. Skromme (1977) states that for the NH TR-70 combine the crop traverses the threshing and separating concaves two or three times. As the two concaves (threshing and separating) are approximately of equal length (Nyborg et al. 1978), the number of traverses Skromme (1977) states is only slightly greater than that calculated above.

7.1.1 Axial-flow combines versus conventional combines

The arc of the concave or wrap for the IH 1460 axial-flow combine is 118°. This is nearly equal to the wrap (116°) for the 1992 JD Maximizer. What makes this an interesting comparison is that the JD Maximizer has a somewhat larger cylinder diameter than the rotor diameter of the IH 1460. This means that the traverse of the crop through the concave is somewhat longer for the combine that utilizes a single transverse cylinder. With more recent models, however, International Harvester has increased both the concave wrap and rotor diameter. It appears that productivity is more a function of the concave wrap and cylinder/rotor diameter than the orientation of the threshing elements.

8. SUMMARY AND CONCLUSIONS

The mean axial velocity of the crop as it traversed the concave and vanes was between 1.6 and 1.7 m/s. The tangential velocity was approximately 1/3 to 1/5 of the peripheral velocity of the rotor.

The average number of times that the crop traverses the concaves is approximately one and the productivity appears to be more a function of the concave wrap and cylinder/rotor diameter rather than the orientation of the threshing elements.

The technique is inappropriate for measuring small changes in crop velocities such as those caused by small changes in the vane angle and rotor speed.

The breaking and crushing of the magnets by the rotor or concave bars was also a serious problem along with their location other than at the periphery of the rotor.

The precision in determining the mean crop velocities in an axial-flow combine is a function of the number of sensors per row and the number of rows. The compromise in terms of cost for the IH 1460 was 96 sensors in two rows.

The sampling rate of microcomputer board running at 2 Mhz was nearly two hundred times faster than the rate needed to determine the crop velocity.

An unknown but remote error occurs with the DAS selecting a higher address when adjacent sensors are triggered at the same time. The size of the error is a function of the sensor spacing.

The necessity to down load the data prior to the next run because of the limited memory of microcomputer was a disadvantage.

9. RECOMMENDATIONS

It is recommended that at least one more row of sensors be mounted in the rotor housing to measure any changes in axial and tangential velocities within vane traverse. The degree of precision required however, determines the number of rows of sensors needed which must be weighed against the cost effects.

The damaging of the expensive magnets and the heat shrink tube requires considerable attention. Any measurement of the crop movement at the separation traverses precedes the solution to the above problem first. A smaller and stronger (physically and magnetically) magnet may perhaps eradicate this problem.

The Data acquisition system (DAS) should be fabricated like a printed circuit board instead of wire wrapped (as in our case) to avoid any loosening of connections. It should also be modified to output two or more sensors triggered at the same time instead of selecting one with the higher address.

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11. APPENDIX A

Tables listing the sensor on/off along the axial direction :

Table 11.1 Sensor on,off along the axial distance at 800 rpm, vane angle 11, replicate 1.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
10	14	5.951	0.000
14	14	5.965	14.00
29	30	6.095	130.0
31	32	6.118	22.60
54	58	6.314	196.0
88	96	6.510	195.9
92	100	6.642	132.6

Table 11.2 Sensor on,off along the axial distance at 800 rpm, vane angle 11, replicate 2.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
38	42	6.0590	0.000
40	44	6.0595	0.520
44	48	6.0840	24.50

Table 11.3 Sensor on,off along the axial distance at 800 rpm, vane angle 11, replicate 3.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
16	16	7.908	0.000
18	18	8.111	202.0
24	24	8.114	3.072
33	38	8.289	175.0
37	42	8.291	2.450
39	44	8.292	0.406

Table 11.4 Sensor on,off along the axial distance at 1000 rpm, vane angle 11, replicate 1.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
29	30	6.2750	0.000
31	32	6.2752	0.278
37	42	6.2760	0.364
96	104	6.4920	215.9

Table 11.5 Sensor on,off along the axial distance at 1000 rpm, vane angle 11, replicate 2.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
26	26	6.0480	0.000
28	28	6.0481	0.104
32	32	6.0540	5.720
49	54	6.2010	146.5
55	60	6.2016	0.624

Table 11.6 Sensor on,off along the axial distance at 1000 rpm, vane angle 11, replicate 3.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
18	18	7.465	0.000
33	38	7.551	85.70
37	42	7.552	0.874

Table 11.7 Sensor on,off along the axial distance at 800 rpm, vane angle 22, replicate 1.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
26	26	5.4210	0.000
28	28	5.4215	0.520
45	52	5.6210	244.0
47	54	5.6215	0.520
78	86	5.8820	260.0
80	88	5.8825	0.520
85	96	5.9960	160.6
87	98	5.9965	0.520

Table 11.8 Sensor on,off along the axial distance at 800 rpm, vane angle 22, replicate 2.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
26	26	5.8118	0.000
28	28	5.8119	0.520
45	52	5.9820	65.80
47	54	5.9825	0.520
82	90	6.2270	244.8
84	92	6.2275	0.520

Table 11.9 Sensor on,off along the axial distance at 800 rpm, vane angle 22, replicate 3.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
66	74	6.782	0.000
70	78	6.784	2.206
81	90	6.908	123.3
87	96	6.953	45.00

Table 11.10 Sensor on,off along the axial distance at 1000 rpm, vane angle 22, replicate 1.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
26	26	6.3590	0.000
28	28	6.3595	0.520
45	50	6.5310	171.0
47	52	6.5315	0.580
88	96	6.7820	251.0
96	104	6.7910	8.923

Table 11.11 Sensor on,off along the axial distance at 1000 rpm, vane angle 22, replicate 2.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
22	22	6.933	0.000
24	24	6.935	1.960
88	96	7.317	382.6
92	100	7.318	0.442

Table 11.12 Sensor on,off along the axial distance at 1000 rpm, vane angle 22, replicate 3.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
37	42	11.286	0.000
52	56	11.390	103.0
56	60	11.430	43.40
66	74	11.501	67.60
70	78	11.505	4.320
72	80	11.510	4.651
74	82	11.510	0.585
85	94	11.596	85.70

Table 11.13 Sensor on,off along the axial distance at 800 rpm, vane angle 33, replicate 1.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
02	02	9.165	0.000
57	64	9.657	492.0
88	96	9.967	310.0

Table 11.14 Sensor on,off along the axial distance at 800 rpm, vane angle 33, replicate 2.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
18	18	7.4800	0.000
20	20	7.4801	0.104
37	42	7.6000	120.6
77	86	7.9760	375.0

Table 11.15 Sensor on,off along the axial distance at 800 rpm, vane angle 33, replicate 3.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
02	02	7.6940	0.000
05	06	7.7750	81.00
40	46	8.0000	224.0
70	78	8.3529	352.9
72	80	8.3530	0.052
80	88	8.3539	0.889
88	96	8.3640	11.00

Table 11.16 Sensor on,off along the axial distance at 1000 rpm, vane angle 33, replicate 1.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
32	32	6.7520	0.000
49	54	6.8390	86.70
51	56	6.8398	0.885
55	60	6.8399	0.060
63	68	6.8499	9.370
82	90	7.0930	144.0
84	92	7.0937	0.520

Table 11.17 Sensor on,off along the axial distance at 1000 rpm, vane angle 33, replicate 2.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
37	42	6.7576	0.000
64	68	7.0420	280.0
81	90	7.2068	164.7

Table 11.18 Sensor on,off along the axial distance at 1000 rpm, vane angle 33, replicate 3.

Sensor #	Distance located (cm)	Trigger time (sec)	Interval time (msec)
25	26	7.6320	0.000
34	38	7.7770	145.6
36	40	7.7775	0.520
64	68	7.8430	35.90
66	74	7.9270	83.30
78	86	8.2340	306.8
80	88	8.2345	0.520

12. APPENDIX B

Axial displacement of the material for concave and vane traverses :

Table 12.1 Mean travel distance of material (for 3 replicates) in concave and vane traverses for rpm 800, vane angle 11 degrees.

Replicate #	Concave traverse		Vane traverse	
	Distance (cm)	Time (msec)	Distance (cm)	Time (msec)
1	16	130	26	196
2	-	-	-	-
3	14	175	-	-
Mean	15	153	26	196

Table 12.2 Mean travel distance of material (for 3 replicates) in concave and vane traverses for rpm 800, vane angle 22 degrees.

Replicate #	Concave traverse		Vane traverse	
	Distance (cm)	Time (msec)	Distance (cm)	Time (msec)
1	28	244	34	260
	12	160	-	-
2	28	066	38	245
3	18	168	-	-
Mean	21.5	160	36	253

Table 12.3 Mean travel distance of material (for 3 replicates) in concave and vane traverses for rpm 800, vane angle 33 degrees.

Replicate #	Concave traverse		Vane traverse	
	Distance (cm)	Time (msec)	Distance (cm)	Time (msec)
1	72	492	32	310
2	22	120	-	-
3	-	-	48	224
Mean	47	306	40	267

Table 12.4 Mean travel distance of material (for 3 replicates) in concave and vane traverses for rpm 1000, vane angle 11 degrees.

Replicate #	Concave traverse		Vane traverse	
	Distance (cm)	Time (msec)	Distance (cm)	Time (msec)
1	-	-	34	216
2	22	147	-	-
3	20	086	-	-
Mean	21	117	34	216

Table 12.5 Mean travel distance of material (for 3 replicates) in concave and vane traverses for rpm 1000, vane angle 22 degrees.

Replicate #	Concave traverse		Vane traverse	
	Distance (cm)	Time (msec)	Distance (cm)	Time (msec)
1	22	171	44	251
2	-	-	-	-
3	12	86	14	103
Mean	17	129	29	177

Table 12.6 Mean travel distance of material (for 3 replicates) in concave and vane traverses for rpm 1000, vane angle 33 degrees.

Replicate #	Concave traverse		Vane traverse	
	Distance (cm)	Time (msec)	Distance (cm)	Time (msec)
1	22	087	36	144
2	22	165	26	280
3	-	-	42	180
Mean	22	126	34	201

13. APPENDIX C

Programme listing :

The following is an Assembly Language programme for the project problem entitled

'Material movement in the threshing section of an axial-flow combine'

Written by .. Anil K. Kukreja

This programme records the data (a 5 byte number) representing the number of a sensor in the first byte space and the time at which this data came in at the next four bytes. The data is coded here in hexadecimal form.

The following segment of the programme defines the constants as are used in naming the different Address locations of the system.

```
ORG    $C000    *Memory address for storing programme.
PORTB  EQU    $1004    *Output port-B for Reset pulse.
PORTE  EQU    $100A    *Input 8-bit data port-E.
TCNT   EQU    $100E    *Location for the timer counter in memory.
TMASK2 EQU    $1024    *Location for the timer mask
OVFLOW EQU    $C090    *Location of the accumulator overflows in memory.
TFLG2  EQU    $1025    *Location of the timer flag in memory.
```

This segment is part of the initialization process of the system. All the memory locations used for storing the data are cleared of any previous data.

```
LDAA   #$00    *Load $00 in Accumulator A.
LDX    #$6000  *Load initial memory location.
LOOP1  STAA 0,X    *Store $00 in memory location.
      INX      *Increment memory location.
      CPX    #$7FFF *Compare until this memory location.
      BLS   LOOP1 *Branch if lower or same to LOOP1

      LDY    #$C090
LOOP2  STAA 0,Y
      INY
      CPY    #$DFFF
      BLS   LOOP2
```

The following segment enables the interrupt. Also, the starting address location for storing the data is defined here.

```
LDY    #$C0A0
```

```
LDAA #10000000
STAA TMASK2
```

In this section, the stack pointer and the interrupt sub-routines are initialized and interrupt mask is cleared for it to be ready in the event of interrupt as a result of overflowing of the timer.

```
LDX  #ISR    *Load interrupt sub-routine(ISR).
STX  $00D1   *Store ISR.
LDS  #$4A    *Load stack pointer.
CLI                      *Clear interrupt mask.
```

This part of the programme sets the output port-B pins to a high state (+5 V). The output here is used as input (Reset pulse) for the Data Acquisition System (DAS) and sets the DAS in the data acquisition mode.

```
BEGIN LDAA #11111111
STAA  PORTB
```

This portion helps read the Interrupt (poll) bit of the DAS and determines if there is any data at the input port-E or not and then, jumps subsequently to the appropriate place in the programme.

```
READPOL LDAA PORTE    *Load input port-E.
        ANDA #10000000 *Logically AND the MSB.
        CMPA #10000000 *Compare the two MSB's.
        BNE  READPOL  *Branch to READPOL if not equal.
```

This section records the 7-bit data and stores at the appropriate memory location.

```
DATA LDAA PORTE
     ANDA #01111111
     STAA 0,Y
     INY
```

This following section records the time and stores near the data recorded earlier.

```
TIME LDX TCNT    *Load timer counter.
     LDD OVFLOW  *Load timer counter overflow.
     STD 0,Y
     INY
     INY
     STX 0,Y
     INY
     INY
```

The Reset pulse is set to low state (+0 V) here momentarily to clear any data appearing at the output port of the DAS and thus setting the system once again ready for any new data resulting from the sensor-magnet

interaction.

```
RESET  LDAA  #$00
        STAA  PORTB
        STAA  PORTB
```

If the data exceeds the available memory locations, the programme is brought to stop here.

```
        CPY   #$7FFA *Check if memory is filled here.
        BLO   CONT  *Branch if lower, to label field CONT.
        CPY   #$7FFF
        BLO   END
CONT    CPY   #$DFFA
        BLO   BEGIN
        LDY   #$6000
        BRA   BEGIN *Branch back to the BEGIN of programme.

END     STOP      *Stop executing the programme.
```

The ISR is activated here every time an overflow occurs in the Timer counter. The programme jumps to ISR, increments the counter and set the interrupt enable subroutine ready for any further interrupts.

```
ISR     LDX   OVFLOW
        INX
        STX   OVFLOW
        LDAA  #$10000000
        STAA  TFLG2
        RTI           *Return from interrupt
```

Note : This programme is first converted to machine language (code) using AS11 assembler programme and the code is then down loaded to the microcomputer board (MC68HC11EVB).

14. APPENDIX D

Table 14.1 Axial and tangential velocities for the two traverses as used in ANOVA analysis using SAS procedures.

OBS	ANGLE	RPM	REP	AXCON	TANCON	AXVANE	TANVANE
1	1	1	1	1.23	5.53	1.32	7.91
2	1	1	2	.	.	.	.
3	1	1	3	0.80	4.11	.	.
4	1	2	1	.	.	1.57	7.17
5	1	2	2	1.49	4.89	.	.
6	1	2	3	2.32	8.37	.	.
7	2	1	1	0.99	3.56	1.30	5.96
8	2	1	2	4.24	10.9	1.55	6.32
9	2	1	3	1.07	4.28	.	.
10	2	2	1	1.28	4.21	1.75	6.17
11	2	2	2	.	.	.	.
12	2	2	3	1.39	8.37	1.36	15.0
13	3	1	1	1.46	1.46	1.03	5.00
14	3	1	2	1.83	6.00	.	.
15	3	1	3	.	.	2.14	6.92
16	3	2	1	2.52	8.27	2.50	10.7
17	3	2	2	1.33	4.36	0.92	5.53
18	3	2	3	.	.	2.33	8.61

Where;

AXVANE : Axial velocity in the vane traverse

TANVANE : Tangential velocity in the vane traverse

AXCON : Axial velocity in the concave traverse

TANCON : Tangential velocity in the concave traverse

Note : The missing values are represented by a dot (.).

15. APPENDIX E

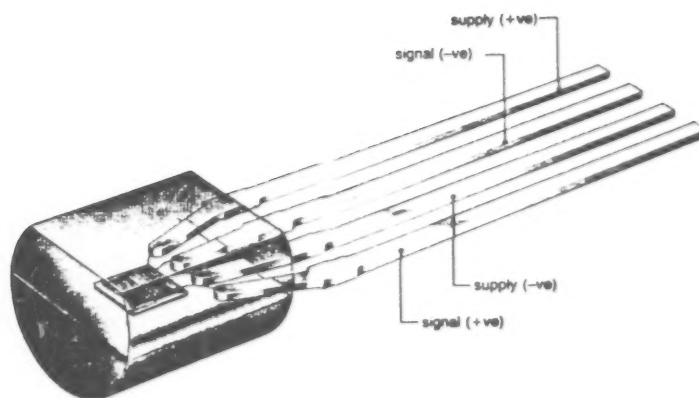


Plate 15.1 A Magneto-resistive sensor (MRS)

MAGNETIC FIELD SENSOR

The KMZ10A is an extremely sensitive magnetic field sensor employing the magneto-resistive effect of thin film permalloy.

Its properties enable this sensor to be used in a wide range of applications for navigation, current and field measurement, revolution counters, angular or linear position measurement and proximity detectors, etc.

QUICK REFERENCE DATA

Operating voltage	V_B	=	5 V
Operating range	H_y	=	± 0.5 kA/m
Auxiliary field	H_x	=	0.5 kA/m
Sensitivity	S	=	$14 \frac{\text{mV/V}}{\text{kA/m}}$
Offset voltage	V_{off}	<	± 1.5 mV/V
Bridge resistance	R_{bridge}	=	0.9 to 1.7 k Ω

MECHANICAL AND ELECTRICAL DATA

Dimensions in mm

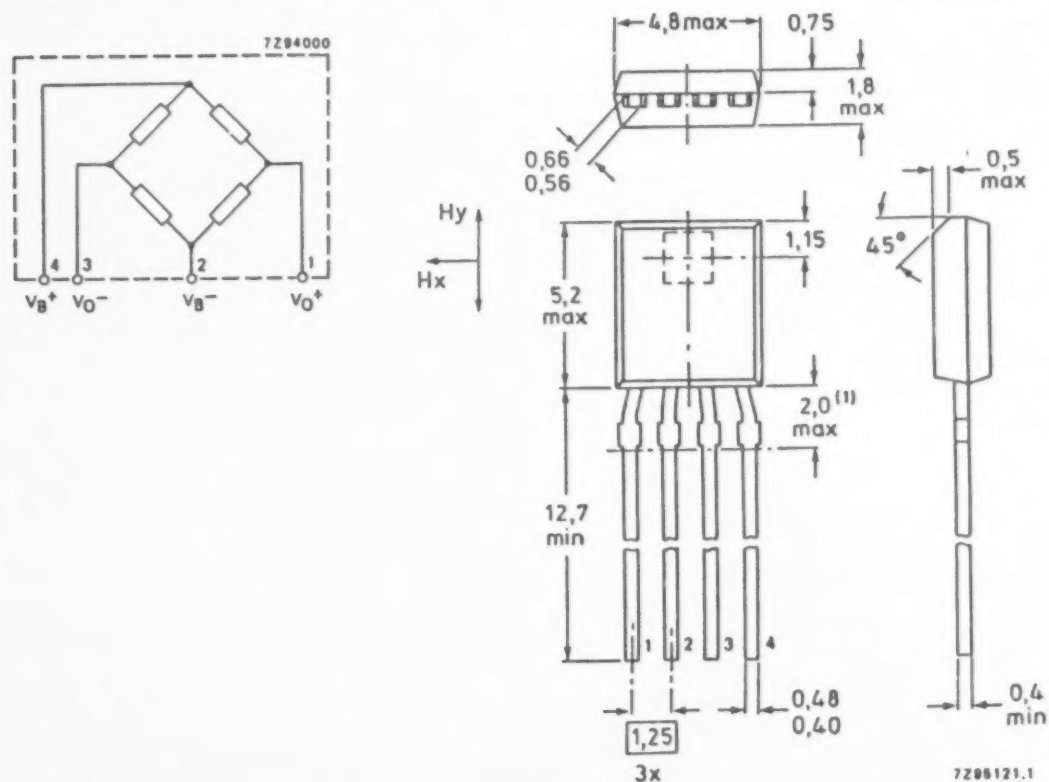


Fig. 1 SOT195.

(1) Terminal dimensions uncontrolled within this area.

RATINGS

Limiting values in accordance with the Absolute Maximum System (IEC 134)

Operating voltage	V_B	max.	9 V
Total power dissipation up to $T_{amb} = 134\text{ }^{\circ}\text{C}$	P_{tot}	max.	90 mW
Storage temperature range	T_{stg}		$-65\text{ to }+150\text{ }^{\circ}\text{C}$
Operating bridge temperature range	T_{bridge}		$-40\text{ to }+150\text{ }^{\circ}\text{C}$

THERMAL RESISTANCE

From junction to ambient	R_{thj-a}	=	180 K/W
--------------------------	-------------	---	---------

CHARACTERISTICS

 $T_{amb} = 25\text{ }^{\circ}\text{C}$ and $H_x = 0.5\text{ kA/m}$ (1) unless otherwise specified

Bridge supply voltage	V_B	=	5 V
Operating range (1)	H_y	=	$\pm 0.5\text{ kA/m}$
Open circuit sensitivity (1)	S	=	11 to 17 $\frac{\text{mV/V}}{\text{kA/m}}$
Temperature coefficient of output voltage $V_B = \text{constant}; T_j = -25\text{ to }+125\text{ }^{\circ}\text{C}$ $I_B = \text{constant}; T_j = -25\text{ to }+125\text{ }^{\circ}\text{C}$	TCV_o VCV_o	typ.	$-0.4\text{ }^{\circ}\text{C/K}$ $-0.15\text{ }^{\circ}\text{C/K}$
Bridge resistance	R_{br}		0.9 to 1.7 k Ω
Temperature coefficient of bridge resistance at $T_j = -25\text{ to }+125\text{ }^{\circ}\text{C}$	TCR_{br}	typ.	0.25 $\text{ }^{\circ}\text{C/K}$
Offset voltage	V_{off}	$\leq$	$\pm 1.5\text{ mV/V}$
Temperature coefficient of offset voltage at $T_{bridge} = -25\text{ to }+125\text{ }^{\circ}\text{C}$	TCV_{off}	$\leq$	$\pm 6\text{ } \frac{\mu\text{V/V}}{\text{K}}$
Linearity deviation of output voltage at $H_y = 0\text{ to } \pm 0.25\text{ kA/m}^{-1}$ $H_y = 0\text{ to } \pm 0.4\text{ kA/m}^{-1}$ $H_y = 0\text{ to } \pm 0.5\text{ kA/m}^{-1}$	FL FL FL	$<$	0.8 % FS 2.5 % FS 4.0 % FS
Hysteresis of output voltage		$<$	0.5 % FS
Operating frequency	f_{max}	=	1 MHz

Note

Before first operation or after operation outside the SOAR (Fig. 2) the sensor has to be reset by application of an auxiliary field $H_x = 3\text{ kA/m}$.

(1) No disturbing field (H_d) allowed; for stable operation under disturbing conditions see Fig. 2 (SOAR) and see Fig. 3 for decrease of sensitivity.

16. APPENDIX F

16.1 Components list for 96 MRS circuits :

The following is the list of the electrical components which is required to interface all the 96 MRS sensors with the data acquisition system.

Part's name	Functional description	Qty. reqd.
1. UA-324PC	Quad low power differential input op-amp.	96
2. Carbon resistors	0.22 mega-ohms	192
	1.0 mega-ohms	96
	1.0 K ohms	192
	10.0 K ohms	288
3. 1N459 A	Diode	96

17. APPENDIX G

17.1 Components list for assembling DAS :

The following is the list of the electrical components required in the assembling of DAS, the quantity required and their functional description.

Part number	Functional name and description	Quantity reqd.
74HC107	Dual J-K flip flop	48
MC14532B	8-Bit priority encoder	14
MC14072B	Dual 4-input 'OR' gate	5
MC14075B	Triple 3-input 'OR' gate	1
MC14008B	4-Bit full adder	1
MC14070B	Quad 2-input 'EXCLUSIVE OR' gate	1
MC 14081B	Quad 2-input 'AND' gate	3
MC14001B	Quad 2-input 'NOR' gate	3
CAPACITOR	Decoupling 0.01 μ F	76
VECTOR BOARD	No copper for mounting IC's (8 $\frac{1}{4}$ " x 17 ")	1
WIRE WRAP	Sockets 14 Pin	61
WIRE WRAP	Sockets 16 Pin	15
R30W-100	White wrapping wire	125 ft.
R30B-100	Blue wrapping wire	125 ft.
R30BLK-100	Black wrapping wire	125 ft.

18. APPENDIX H

Technical data on CMOS devices (semiconductors) :

18.1 Dual J-K flip-flop with Reset

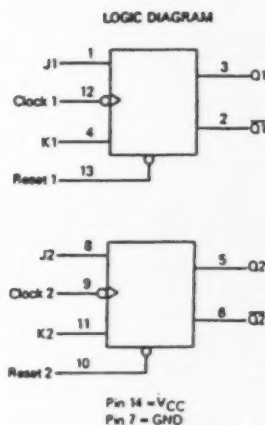
MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

Dual J-K Flip-Flop with Reset High-Performance Silicon-Gate CMOS

The MC54/74HC107 is identical in pinout to the LS107. The device inputs are compatible with standard CMOS outputs; with pullup resistors, they are compatible with LSTTL outputs.

Each flip-flop is negative-edge clocked and has an active-low asynchronous reset. The HC107 is identical in function to the HC73, but has a different pinout.

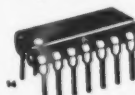
- Output Drive Capability: 10 LSTTL Loads
- Outputs Directly Interface to CMOS, NMOS, and TTL
- Operating Voltage Range: 2 to 6 V
- Low Input Current: 1 μ A
- High Noise Immunity Characteristic of CMOS Devices
- In Compliance with the Requirements Defined by JEDEC Standard No. 7A
- Chip Complexity: 92 FETs or 23 Equivalent Gates



MC54/74HC107



J SUFFIX
CERAMIC
CASE 632-08



N SUFFIX
PLASTIC
CASE 646-08



D SUFFIX
SOIC
CASE 751A-02

ORDERING INFORMATION

MC74HC00XN	Plastic
MC54HC00XJ	Ceramic
MC74HC00XD	SOIC

$T_A = -55^\circ$ to 125°C for all packages.
Dimensions in Chapter 7.

PIN ASSIGNMENT

J1	1	14	VCC
$\overline{Q1}$	2	13	Reset 1
Q1	3	12	Clock 1
K1	4	11	K2
Q2	5	10	Reset 2
$\overline{Q2}$	6	9	Clock 2
GND	7	8	J2

FUNCTION TABLE

Inputs				Outputs	
Reset	Clock	J	K	Q	$\overline{Q}$
L	X	X	X	L	H
H	$\sim$	L	L	No Change	H
H	$\sim$	L	H	L	H
H	$\sim$	H	L	H	L
H	$\sim$	H	H	Toggle	
H	L	X	X	No Change	
H	H	X	X	No Change	
H	$\sim$	X	X	No Change	

18.2 8-Bit Priority Encoder



MOTOROLA

MC14532B

8-BIT PRIORITY ENCODER

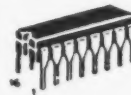
The MC14532B is constructed with complementary MOS (CMOS) enhancement mode devices. The primary function of a priority encoder is to provide a binary address for the active input with the highest priority. Eight data inputs (D0 thru D7) and an enable input (E_{in}) are provided. Five outputs are available, three are address outputs (Q0 thru Q2), one group select (GS) and one enable output (E_{out}).

- Diode Protection on All Inputs
- Supply Voltage Range = 3.0 Vdc to 18 Vdc
- Capable of Driving Two Low-power TTL Loads or One Low-Power Schottky TTL Load over the Rated Temperature Range

CMOS MSI

(LOW-POWER COMPLEMENTARY MOS)

8-BIT PRIORITY ENCODER



L SUFFIX
CERAMIC PACKAGE
CASE 620



P SUFFIX
PLASTIC PACKAGE
CASE 648

ORDERING INFORMATION

A Series: -55°C to +125°C
MC14XXXBAL (Ceramic Package Only)

C Series: -40°C to +85°C
MC14XXXBCP (Plastic Package)
MC14XXXBCL (Ceramic Package)

MAXIMUM RATINGS* (Voltages Referenced to V_{SS})

Symbol	Parameter	Value	Unit
V_{DD}	DC Supply Voltage	-0.5 to +18.0	V
V_{in} , V_{out}	Input or Output Voltage (DC or Transient)	-0.5 to V_{DD} + 0.5	V
I_{in} , I_{out}	Input or Output Current (DC or Transient) per Pin	±10	mA
P_D	Power Dissipation, per Package†	500	mW
T_{stg}	Storage Temperature	-65 to +150	°C
T_L	Lead Temperature (8-Second Soldering)	260	°C

*Maximum Ratings are those values beyond which damage to the device may occur.
†Temperature Derating: Plastic P Package - 12mW/°C from 85°C to 150°C
Ceramic L Package - 12mW/°C from 100°C to 125°C

TRUTH TABLE

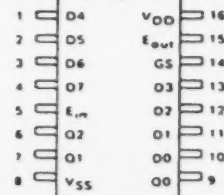
INPUT									OUTPUT					
E_{in}	D7	D6	D5	D4	D3	D2	D1	D0	GS	Q2	Q1	Q0	E_{out}	
0	X	X	X	X	X	X	X	X	0	0	0	0	0	
1	0	0	0	0	0	0	0	0	0	0	0	0	1	
1	1	X	X	X	X	X	X	X	1	1	1	1	0	
1	0	1	X	X	X	X	X	X	1	1	1	0	0	
1	0	0	1	X	X	X	X	X	1	1	0	1	0	
1	0	0	0	1	X	X	X	X	1	1	0	0	0	
1	0	0	0	0	1	X	X	X	1	0	1	1	0	
1	0	0	0	0	0	1	X	X	1	0	1	0	0	
1	0	0	0	0	0	0	1	X	1	0	0	1	0	
1	0	0	0	0	0	0	0	1	1	0	0	0	0	

X = Don't Care

This device contains protection circuitry to guard against damage due to high static voltages or electric fields. However, precautions must be taken to avoid applications of any voltage higher than maximum rated voltages to this high-impedance circuit. For proper operation, V_{in} and V_{out} should be constrained to the range $V_{SS} \leq (V_{in} \text{ or } V_{out}) \leq V_{DD}$.

Unused inputs must always be tied to an appropriate logic voltage level (e.g., either V_{SS} or V_{DD}). Unused outputs must be left open.

PIN ASSIGNMENT



18.3 4-Bit Full Adder



MOTOROLA

4-BIT FULL ADDER

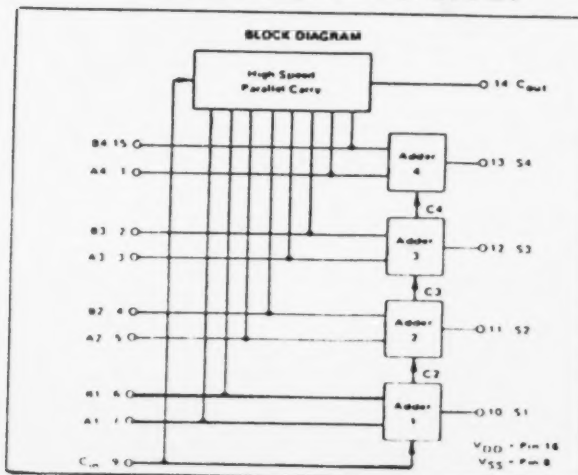
The MC14008B 4-bit full adder is constructed with MOS P-channel and N-channel enhancement mode devices in a single monolithic structure. This device consists of four full adders with fast internal look-ahead carry output. It is useful in binary addition and other arithmetic applications. The fast parallel carry output bit allows high-speed operation when used with other adders in a system.

- Look-Ahead Carry Output
- Diode Protection on All Inputs
- All Outputs Buffered
- Supply Voltage Range = 3.0 Vdc to 18 Vdc
- Capable of Driving Two Low-power TTL Loads or One Low-power Schottky TTL Load Over the Rated Temperature Range
- Pin-for-Pin Replacement for CD4008B

MAXIMUM RATINGS* (Voltages Referenced to V_{SS})

Symbol	Parameter	Value	Unit
V_{DD}	DC Supply Voltage	-0.5 to +18.0	V
V_{in}, V_{out}	Input or Output Voltage (DC or Transient)	-0.5 to $V_{DD} + 0.5$	V
I_{in}, I_{out}	Input or Output Current (DC or Transient), per Pin	±10	mA
P_D	Power Dissipation, per Package†	500	mW
T_{stg}	Storage Temperature	-65 to +150	°C
T_L	Lead Temperature (8-Second Soldering)	260	°C

*Maximum Ratings are those values beyond which damage to the device may occur.
 †Temperature Derating: Plastic P Package - 12mW/°C from 85°C to 150°C
 Ceramic L Package - 12mW/°C from 100°C to 125°C



MC14008B

CMOS MSI

(LOW POWER COMPLEMENTARY MOS)

4-BIT FULL ADDER



L SUFFIX
CERAMIC PACKAGE
CASE 620

P SUFFIX
PLASTIC PACKAGE
CASE 648

ORDERING INFORMATION

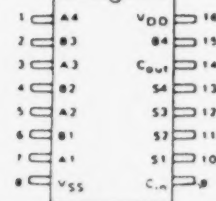
A Series - 55°C to +125°C
 MC14XXXBAL (Ceramic Package Only)

C Series - 40°C to +85°C
 MC14XXXBCP (Plastic Package)
 MC14XXXBCL (Ceramic Package)

TRUTH TABLE (One Stage)

C_{in}	B	A	C_{out}	S
0	0	0	0	0
0	0	1	0	1
0	1	0	0	1
0	1	1	1	0
1	0	0	0	1
1	0	1	1	0
1	1	0	1	0
1	1	1	1	1

PIN ASSIGNMENT




MOTOROLA
CMOS SSI
QUAD EXCLUSIVE "OR" AND "NOR" GATES

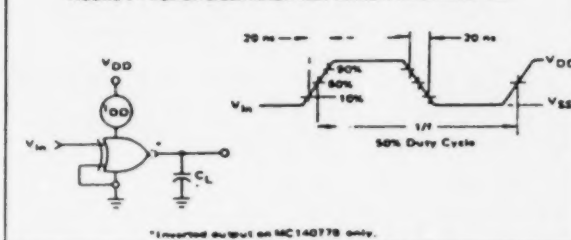
The MC14070B quad exclusive OR gate and the MC14077B quad exclusive NOR gate are constructed with MOS P-channel and N-channel enhancement mode devices in a single monolithic structure. These complementary MOS logic gates find primary use where low power dissipation and/or high noise immunity is desired.

- Supply Voltage Range = 3.0 Vdc to 18 Vdc
- All Outputs Buffered
- Capable of Driving Two Low-Power TTL Loads or One Low-Power Schottky TTL Load Over the Rated Temperature Range
- Double Diode Protection on All Inputs
- MC14070B — Replacement for CD4030B and CD4070B Types
- MC14077B — Replacement for CD4077B Type

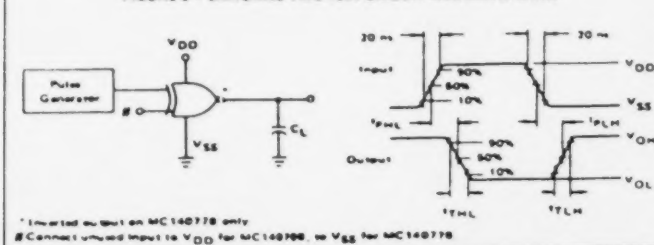
MAXIMUM RATINGS* (Voltages Referenced to V_{SS})

Symbol	Parameter	Value	Unit
V_{DD}	DC Supply Voltage	-0.5 to +18.0	V
V_{in}, V_{out}	Input or Output Voltage (DC or Transient)	-0.5 to $V_{DD} + 0.5$	V
I_{in}, I_{out}	Input or Output Current (DC or Transient), per Pin	± 10	mA
P_D	Power Dissipation, per Package†	500	mW
T_{stg}	Storage Temperature	-65 to +150	°C
T_L	Lead Temperature (8-Second Soldering)	260	°C

*Maximum Ratings are those values beyond which damage to the device may occur.
 †Temperature Derating: Plastic "P" Package: -12mW/°C from 85°C to 125°C
 Ceramic "L" Package: -12mW/°C from 100°C to 125°C

FIGURE 1 — POWER DISSIPATION TEST CIRCUIT AND WAVEFORM


*Inverted output on MC14077B only.

FIGURE 2 — SWITCHING TIME TEST CIRCUIT AND WAVEFORMS


*Inverted output on MC14077B only.
 †Connect unused input to V_{DD} for MC14070B, or V_{SS} for MC14077B

MC14070B
QUAD EXCLUSIVE "OR" GATE
MC14077B
QUAD EXCLUSIVE "NOR" GATE

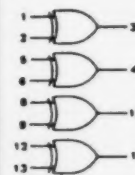
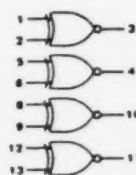

CASE 632
L SUFFIX
CERAMIC PACKAGE

CASE 646
P SUFFIX
PLASTIC PACKAGE

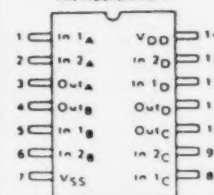
ORDERING INFORMATION

A Series: -55°C to +125°C
 MC14070BAL (Ceramic Package Only)

C Series: -40°C to +85°C
 MC14070BCP (Plastic Package)
 MC14070BC (Ceramic Package)

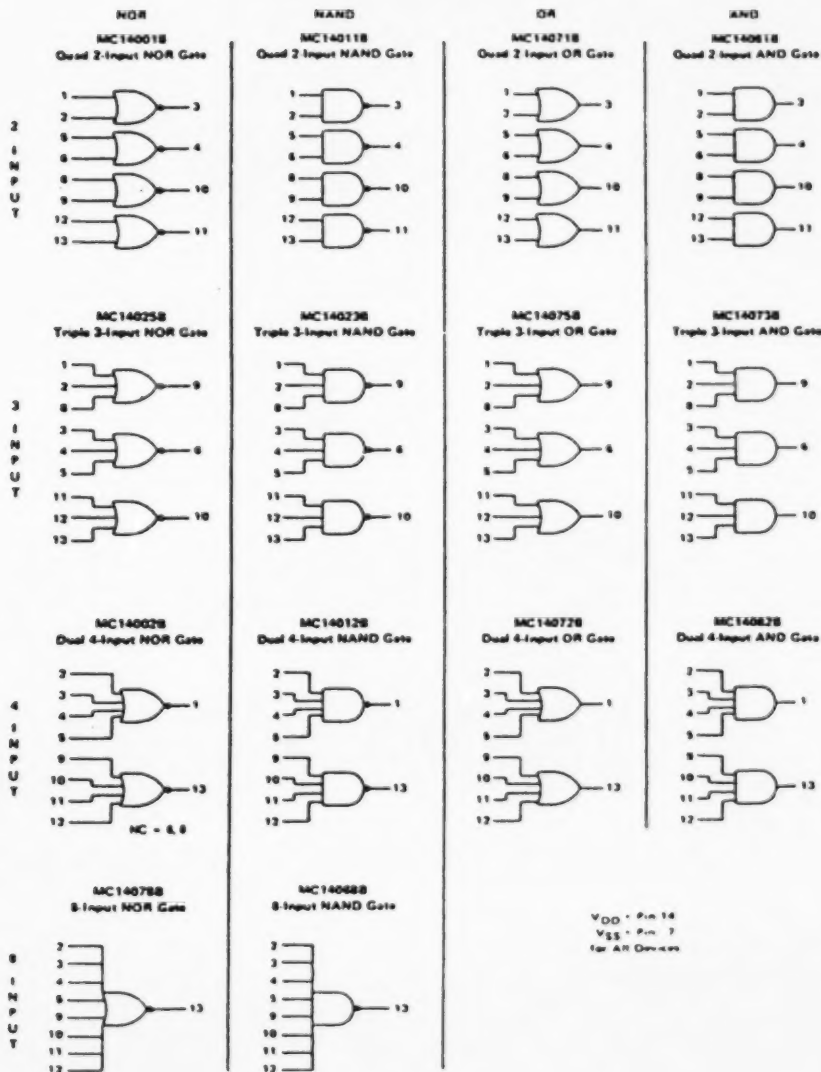
MC14070B
Quad Exclusive OR Gate

MC14077B
Quad Exclusive NOR Gate


V_{DD} = Pin 14
 V_{SS} = Pin 7
 (Both Devices)

PIN ASSIGNMENT


CMOS B-SERIES GATES

LOGIC DIAGRAMS



19. APPENDIX I

Data listing for the different runs :

19.1 : Data for the run # 1

rpm = 800, vane angle 11°, replicate # 1

```

09 00 B5 9F E0 09 00 B5 A0 48 09 00 B5 A0 B0 09 00 B5 A1 18 09 00 B5 A1
80 09 00 B5 A1 E8 09 00 B5 A2 50 09 00 B5 A2 B8 09 00 B5 A3 20 09 00 B5
A3 88 09 00 B5 A3 F0 09 00 B5 A4 58 0D 00 B6 0B 55 0D 00 B6 0B BD 0D 00
B6 0C 25 09 00 B6 34 99 09 00 B6 35 01 09 00 B6 35 69 B6 38 41 09 00 B6
38 A9 09 00 B6 39 11 09 00 B6 09 00 B6 39 E1 09 00 B6 3A 49 09 00 B6 3A
B1 09 00 B6 3B 19 09 00 B6 3B 81 0D 00 B6 48 8B 0D 00 B6 48 F3 0D 00 B6
49 5B 0D 00 B6 49 C3 0D 00 B6 4A 2B 0D 00 B6 4A 93 0D 00 B6 4A FB 0D 00
B6 4B 63 0D 00 B6 4B CB 0D 00 B6 4C 33 0D 00 B6 4C 9B 0D 00 B6 4D 03 0D
00 B6 4D 6B 0D 00 B6 4D D3 0D 00 B6 4E 3B 0D 00 B6 4E A3 0D 00 B6 4F 0B
1C 00 BA B5 A3 1C 00 BA B6 0B 1C 00 BA B6 73 1E 00 BA B6 DB 1E 00 BA D5
41 1E 00 BA D5 A9 1E 00 BA D6 11 1E 00 BA D6 79 1E 00 BA D6 E1 1E 00 BA
D7 49 1E 00 BA D7 B1 1E 00 BA D8 19 1E 00 BA D8 81 1E 00 BA D8 E9 1E 00
BA D9 51 1E 00 BA D9 B9 1C 00 BB 7D 36 1E 00 BB 7D 9E 1E 00 BB 7E 06 1E
00 BB 7E 6E 1E 00 BB 7E D6 1E 00 BB 7F 49 1E 00 BB 7F B1 1E 00 BB 80 19
1E 00 BB 80 81 1E 00 BB 80 E9 1E 00 BB 81 51 1E 00 BB 81 B9 1E 00 BB 82
21 1E 00 BB 82 89 1E 00 BB 82 F1 1E 00 BB 83 59 1E 00 BB 83 C1 1E 00 BB
84 29 1E 00 BB 84 91 1E 00 BB 84 F9 1E 00 BB 85 61 1E 00 BB 85 C9 1C 00
BC 19 97 1C 00 BC 19 FF 1C 00 BC 1A 67 1E 00 BC 1A CF 1E 00 BC 1B 37 1E
00 BC 1B 9F 1E 00 BC 1C 07 1E 00 BC 1C 6F 1E 00 BC 1C D7 1E 00 BC 1D 3F
1E 00 BC 1D A7 1E 00 BC 1E 0F 1E 00 BC 1E 77 1E 00 BC 1E DF 1E 00 BC 1F
47 1E 00 BC 1F AF 1E 00 BC 20 17 1E 00 BC 20 7F 1E 00 BC 20 E7 1E 00 BC
21 4F 1E 00 BC 21 B7 1E 00 BC 22 1F 1E 00 BC 22 87 1E 00 BC 22 EF 1E 00
BC 23 57 1E 00 BC 23 BF 1E 00 BC 24 27 1E 00 BC 24 8F 1E 00 BC 24 F7 1E
1E 00 BC 25 C7 1E 00 BC 26 2F 1E 00 BC 26 97 1E 00 BC 26 FF 1E 00 BC 27
67 1E 00 BC 27 CF 1E 00 BC 28 37 1E 00 BC 28 9F 1E 00 BC 29 07 1E 00 BC
29 6F 1E 00 BC 29 D7 1E 00 BC 2A 3F 1E 00 BC 2A A7 1E 00 BC 2B 0F 1E 00
BC 2B 77 1E 00 BC 2B DF 1E 00 BC 2C 47 1E 00 BC 2C AF 1E 00 BC 2D 17 1E
00 BC 2D 7F 1E 00 BC 2D E7 1E 00 BC 2E 4F 1E 00 BC 2E B7 1E 00 BC 2F 1F
1E 00 BC 2F 87 1E 00 BC 2F EF 1E 00 BC 30 57 1E 00 BC 30 BF 1E 00 BC 31
27 1E 00 BC 31 8F 1E 00 BC 31 F7 1E 00 BC 32 5F 1E 00 BC 32 C7 1E 00 BC
33 2F 57 00 C4 B1 55 57 00 C4 B1 BD 57 00 C4 B2 25 57 00 C4 B2 8D 57 00
C4 B2 F5 5B 00 C4 BE 5D 5B 00 C4 BE C5 5B 00 C4 BF 2D 5B 00 C4 BF 95 5B
00 C4 BF FD 5B 00 C4 D1 27 5B 00 C4 D1 8F

```

19.2 : Data for the run # 2

rpm = 1000, vane angle = 11°, replicate # 1

28 00 13 D5 6B 28 00 13 D5 D3 28 00 A9 FA 72 20 00 BF 7D BA 1C 00 BF 85
02 1C 00 BF 85 6A 1C 00 BF 85 D2 1C 00 BF 86 3A 1E 00 BF 86 A2 1E 00 BF
87 0A 1E 00 BF 87 72 1E 00 BF 87 DA 1C 00 BF 88 42 1C 00 BF 88 AA 24 00
BF 89 12 24 00 BF 89 7A 24 00 BF 89 E2 24 00 BF 8A 4A 1C 00 BF 8A B2 5F
00 C6 20 9E 5F 00 C6 21 06 5F 00 C6 21 6E 5F 00 C6 21 D6 5F 00 C6 38 F9
5F 00 C6 39 61 5F 00 C6 39 C9 5F 00 C6 3A 31 5F 00 C6 3A 99 5F 00 C6 3B
01 5F 00 C6 3B 69 5F 00 C6 3B D1 5F 00 C6 3C 39

19.3 : Data for the run # 3

rpm = 800, vane angle = 11°, replicate # 2

```

25 00 B8 EB D6 27 00 B8 EC 3E 27 00 B8 EC A6 27 00 B8 ED 0E 27 00 B8 ED
76 27 00 B8 ED DE 27 00 B8 EE 46 27 00 B9 34 59 27 00 B9 34 C1 27 00 B9
35 29 27 00 B9 35 91 27 00 B9 35 F9 27 00 B9 36 61 27 00 B9 36 C9 27 00
B9 37 31 27 00 B9 37 99 27 00 B9 38 01 27 00 B9 38 69 27 00 B9 38 D1 27
00 B9 3D 49 27 00 B9 3D B1 27 00 B9 3E 19 27 00 B9 3E 81 27 00 B9 3E E9
27 00 B9 3F 51 27 00 B9 3F B9 27 00 B9 40 21 27 00 B9 40 89 27 00 B9 40
F1 27 00 B9 41 59 27 00 B9 41 C1 27 00 B9 42 29 27 00 B9 42 91 27 00 B9
42 F9 27 00 B9 43 61 27 00 B9 43 C9 27 00 B9 44 31 27 00 B9 44 99 27 00
B9 45 01 27 00 B9 45 69 27 00 B9 45 D1 27 00 B9 46 39 27 00 B9 46 A1 27
00 B9 47 09 27 00 B9 47 71 27 00 B9 47 D9 27 00 B9 48 41 27 00 B9 48 A9
27 00 B9 49 11 27 00 B9 49 79 27 00 B9 49 E1 27 00 B9 4A 49 27 00 B9 4A
B1 27 00 B9 4B 19 27 00 B9 4B 81 27 00 B9 4B E9 27 00 B9 4C 51 27 00 B9
4C B9 27 00 B9 4D 21 27 00 B9 4D 89 27 00 B9 4D F1 27 00 B9 4E 59 27 00
B9 4E C1 27 00 B9 4F 29 27 00 B9 4F 91 27 00 B9 4F F9 27 00 B9 50 61 27
00 B9 50 C9 27 00 B9 51 31 27 00 B9 54 DD 27 00 B9 55 45 27 00 B9 55 AD
27 00 B9 56 15 27 00 B9 56 7D 27 00 B9 56 E5 27 00 B9 57 4D 27 00 B9 96
7C 27 00 B9 96 E4 27 00 B9 97 4C 27 00 B9 97 B4 27 00 B9 98 1C 27 00 B9
98 84 27 00 B9 98 EC 2B 00 B9 AC 05 2B 00 B9 AC 6D 2B 00 B9 AC D5 27 00
B9 E3 2A 27 00 B9 E3 92 27 00 B9 E3 FA 27 00 B9 E4 62 27 00 B9 E4 CA 27
00 B9 E5 32 27 00 B9 E5 9A 27 00 B9 E6 02 27 00 B9 E6 6A 27 00 B9 E6 D2
27 00 B9 E7 3A 27 00 B9 E7 A2 27 00 B9 E8 0A 27 00 B9 E8 72 2B 00 B9 E8
DA 2B 00 B9 E9 42 2B 00 B9 E9 AA 2B 00 B9 EA 12 2B 00 B9 EA 7A 2B

```

19.4 : Data for the run # 4

rpm = 1000, vane angle = 11°, replicate # 2

48 00 3D 9B 04 48 00 3D AB AA 28 00 8F FC 8A 19 00 B8 96 F4 19 00 B8 97
5C 1B 00 B8 97 C4 1B 00 B8 98 2C 1B 00 B8 98 94 1B 00 B8 98 FC 1B 00 B8
9B 8A 1B 00 B8 9B F2 1B 00 B8 9C 5A 1B 00 B8 B0 5A 1F 00 B8 C4 0D 1F 00
B8 C4 75 1F 00 B8 C4 DD 1F 00 B8 C5 45 1B 00 B8 FB 58 1B 00 B8 FB C0 1B
00 B8 FC 28 1B 00 B8 FC 90 1B 00 B8 FC F8 1B 00 B8 FD 60 1F 00 B9 0D F4
1F 00 B9 0E 5C 1F 00 B9 0E C4 1B 00 B9 50 EA 1B 00 B9 51 52 1B 00 B9 51
BA 1B 00 B9 52 22 1F 00 B9 55 4A 1F 00 B9 55 B2 1F 00 B9 56 1A 1F 00 B9
56 82 1F 00 B9 E0 28 1F 00 B9 E0 90 1F 00 B9 E0 F8 1F 00 B9 E1 60 1F 00
B9 E1 C8 1F 00 B9 E2 30 1F 00 B9 E2 98 1F 00 B9 E3 00 1F 00 B9 E3 68 1F
00 B9 E3 D0 1F 00 B9 E4 38 1F 00 B9 E4 A0 30 00 BD 3D 6B 36 00 BD 42 4B
36 00 BD 45 F7 32 00 BD 48 9B 36 00 BD 4A 9A 36 00 BD 4F A6 36 00 BD 59
8D 36 00 BD 59 F5 36 00 BD 5A 5D 36 00 BD 5A C5 36 00 BD 5B 2D 48 00 DA
F9 5B 48 00 F8 58 37 48 00 F8 5A AF 28 00 FD 60 7E 28 00 FD 61 75 28 01
09 FD 2D 28 01 09 FD F8

19.5 : Data for the run # 5

rpm = 800, vane angle = 11°, replicate # 3

11 00 F7 09 22 11 00 F7 09 8A 11 00 F7 09 F2 11 00 F7 0A 5A 11 00 F7 0A
C2 11 00 F7 0B 2A 11 00 F7 0B 92 11 00 F7 0B FA 11 00 F7 0C 62 11 00 F7
17 1A 11 00 F7 17 82 11 00 F7 17 EA 11 00 F7 18 52 11 00 F7 18 BA 11 00
F7 19 22 11 00 F7 19 8A 11 00 F7 19 F2 11 00 F7 1A 5A 11 00 F7 33 40 11
00 F7 6F 6D 11 00 F7 6F D5 11 00 F7 70 3D 0F 00 F7 7B BB 0F 00 F7 7C 23
0F 00 F7 7C 8B 0F 00 F7 7C F3 0F 00 F7 7D 5B 0F 00 F7 7D C3 0F 00 F7 7E
2B 0F 00 F7 7E 93 0F 00 F7 7E FB 0F 00 F7 7F 63 11 00 F7 88 42 17 00 F7
9F E9 17 00 F7 A0 51 17 00 F7 A0 B9 17 00 F7 A1 21 20 00 FC F6 5A 20 00
FC F6 C2 20 00 FD 02 9C 24 00 FD 09 E4 24 00 FD 0C A9 26 00 FD 0D 11 24
00 FD 14 38 24 00 FD 14 A0 24 00 FD 18 D0 24 00 FD 2B 44 20 00 FD 2D 38
24 00 FD 39 BE 20 00 FD 3A 26 20 00 FD 3A 8E 20 00 FD 3F F2 24 00 FD 47
BE 24 00 FD 48 26

19.6 : Data for the run # 6

rpm = 1000, vane angle = 11°, replicate # 3

11 00 E3 D4 78 11 00 E3 D4 E0 11 00 E3 DE E8 24 00 E6 6E 1E 24 00 E6 6E
86 20 00 E6 72 27 24 00 E6 74 7E 24 00 E6 78 FB 24 00 E6 7E 1D

19.7 : Data for the run # 7

rpm = 800, vane angle = 22°, replicate # 1

19 00 A5 76 E9 1B 00 A5 77 51 1B 00 A5 77 B9 1B 00 A5 78 21 1B 00 A5 78
89 1B 00 A5 78 F1 1B 00 A5 79 59 1B 00 A5 79 C1 1B 00 A5 7A 29 1B 00 A5
7A 91 1B 00 A5 7A F9 1B 00 A5 7B 61 1B 00 A5 7B C9 1B 00 A5 D0 1C 1B 00
A6 2D F2 1B 00 A6 34 74 1B 00 A6 8D 08 1B 00 A6 8D 70 1B 00 A6 C9 19 1B
00 A6 C9 81 1B 00 A6 C9 E9 1B 00 A6 CA 51 1B 00 A6 CA B9 1B 00 A6 CB 21
1B 00 A6 CB 89 1B 00 A6 CB F1 1B 00 A6 CC 59 1B 00 A6 CC C1 1B 00 A6 CD
29 1B 00 A6 CD 91 1B 00 A6 CD F9 2C 00 AB 8D DF 2E 00 AB 8E 47 2E 00 AB
96 EF 4D 00 B3 82 4D 4F 00 B3 82 B5 4F 00 B3 83 1D 4F 00 B3 83 85 4F 00
B3 83 ED 4F 00 B3 84 55 4F 00 B3 84 BD 4F 00 B3 85 25 4F 00 B3 85 8D 4F
00 B3 85 F5 4F 00 B3 86 5D 4F 00 B3 86 C5 4F 00 B3 87 38 4F 00 B3 A6 7A
4F 00 B3 A6 E2 4F 00 B3 A7 4A 4F 00 B3 A7 B2 4F 00 B3 A8 1A 4F 00 B3 A8
82 4F 00 B3 A8 EA 4F 00 B3 A9 52 4F 00 B3 A9 BA 4F 00 B3 AA 22 4F 00 B3
AA 8A 4F 00 B3 AA F2 4F 00 B3 AB 5A 4F 00 B3 AB C2 4F 00 B3 AC 2A 4F 00
B3 AC 92 4F 00 B3 AC FA 4F 00 B3 AD 62 4F 00 B3 AD CA 4F 00 B3 AE 32 4F
00 B3 AE 9A 4F 00 B3 AF 02 4F 00 B3 AF 6A 4F 00 B3 AF D2 4F 00 B3 B0 3A
4F 00 B3 B0 A2 4F 00 B3 B1 0A 4F 00 B3 B1 72 4F 00 B3 B1 DA 54 00 B7 02
70 56 00 B7 02 D8 56 00 B7 03 40 56 00 B7 03 A8 56 00 B7 07 28 56 00 B7
07 90 56 00 B7 07 F8 56 00 B7 08 60 56 00 B7 08 C8 56 00 B7 09 30 56 00
B7 09 98 56 00 B7 0A 00 56 00 B7 0B 70 56 00 B7 0B D8 54 00 B7 0F 84 54
00 B7 0F EC 54 00 B7 10 54 56 00 B7 10 DD 54 00 B7 13 FA 54 00 B7 14 62
54 00 B7 14 CA 56 00 B7 1B 0A 56 00 B7 29 F8 56 00 B7 2A 60 56 00 B7 2A
C8 56 00 B7 2B 30 56 00 B7 2B 98

19.8 : Data for the run # 8

rpm = 1000, vane angle 22°, replicate # 1

19 00 C2 12 C6 1B 00 C2 13 2E 1B 00 C2 13 96 1B 00 C2 13 FE 1B 00 C2 14
66 1B 00 C2 14 CE 1B 00 C2 15 36 1B 00 C2 15 9E 1B 00 C2 63 69 1B 00 C2
63 D1 1B 00 C2 64 39 1B 00 C2 64 A1 1B 00 C2 65 09 1B 00 C2 65 71 2C 00
C7 51 99 2E 00 C7 56 21 2E 00 C7 5A 04 2E 00 C7 5B 74 57 00 CE FF 7A 57
00 CE FF ED 57 00 CF 00 85 57 00 CF 00 ED 57 00 CF 01 55 57 00 CF 01 BD
57 00 CF 02 25 57 00 CF 02 8D 57 00 CF 02 F5 57 00 CF 03 5D 57 00 CF 03
C5 57 00 CF 04 2D 57 00 CF 04 95 57 00 CF 04 FD 57 00 CF 05 65 57 00 CF
05 CD 57 00 CF 06 35 57 00 CF 06 9D 57 00 CF 07 05 57 00 CF 07 6D 57 00
CF 07 D5 57 00 CF 08 3D 57 00 CF 08 A5 57 00 CF 09 0D 57 00 CF 09 75 57
00 CF 09 DD 57 00 CF 0A 45 57 00 CF 0A AD 57 00 CF 0B 15 57 00 CF 0B 7D
57 00 CF 0B F0 57 00 CF 0C 58 57 00 CF 0C C0 57 00 CF 39 07 57 00 CF 39
6F 57 00 CF 39 D7 57 00 CF 3A 3F 57 00 CF 3A A7 57 00 CF 3B 0F 57 00 CF
3B 77 57 00 CF 3B DF 57 00 CF 3C 47 5F 00 CF 45 31 5F 00 CF 45 99 5F 00
CF 46 01 5F 00 CF 46 69 5F 00 CF 46 D1 5F 00 CF 47 39 5F 00 CF 47 A1 5F
00 CF 48 09 5F 00 CF 48 71 5F 00 CF 48 D9 5F 00 CF 49 41 5F 00 CF 49 A9
5F 00 CF 4A 11

19.9 : Data for the run # 9

rpm = 800, vane angle = 22°, replicate # 2

48 00 8E 29 65 48 00 8E 2C F0 19 00 B1 5D 6E 1B 00 B1 5D D6 1B 00 B1 5E
3E 1B 00 B1 5E A6 1B 00 B1 5F 0E 1B 00 B1 5F 76 1B 00 B1 5F DE 1B 00 B1
60 46 1B 00 B1 60 AE 1B 00 B1 61 16 1B 00 B1 61 7E 1B 00 B1 61 E6 1B 00
B1 62 4E 17 00 B1 93 44 17 00 B1 93 AC 17 00 B1 A3 08 1B 00 B1 A9 AB 1B
00 B1 E5 8B 1B 00 B1 E5 F3 1B 00 B1 E6 5B 1B 00 B2 0D 9F 2C 00 B6 94 50
2E 00 B6 94 B8 2E 00 B6 95 20 2E 00 B6 95 88 2E 00 B6 F8 CF 2E 00 B6 F9
37 2E 00 B6 F9 D6 2E 00 B7 01 6F 2E 00 B7 03 8F 2E 00 B7 04 DE 24 00 B7
05 46 2E 00 B7 08 A5 24 00 B7 0A F1 2E 00 B7 14 28 51 00 BE 0D DA 53 00
BE 0E 42 53 00 BE 0E AA 53 00 BE 0F 12 53 00 BE 0F 7A 53 00 BE 20 C5 53
00 BE 21 2D 53 00 BE 21 95 53 00 BE 21 FD 53 00 BE 22 65 53 00 BE 22 CD

19.10 : Data for the run # 10

rpm = 1000, vane angle = 22°, replicate # 2

15 00 D3 95 F8 17 00 D3 A5 49 17 00 D3 A5 B1 17 00 D3 A6 19 17 00 D3 A6
81 17 00 D3 A6 E9 17 00 D3 A7 51 17 00 D3 A7 B9 17 00 D3 A8 21 17 00 D3
A8 89 17 00 D3 A8 F1 17 00 D3 A9 59 17 00 D3 A9 C1 17 00 D3 AA 29 17 00
D3 AA 91 17 00 D3 AA F9 17 00 D3 B1 E1 17 00 D3 B2 49 17 00 D3 B2 B1 17
00 D3 B3 19 17 00 D3 B3 81 17 00 D3 B3 E9 17 00 D3 B4 51 17 00 D3 B4 B9
17 00 D3 B5 21 17 00 D3 B5 89 17 00 D3 B5 F1 17 00 D3 B6 59 17 00 D3 B6
C1 17 00 D3 B7 29 17 00 D3 B7 91 17 00 D3 B7 F9 17 00 D3 B8 61 17 00 D3
B8 C9 17 00 D3 B9 31 17 00 D3 B9 A4 17 00 D3 BA 17 17 00 D3 BA AB 17 00
D3 D1 76 17 00 D3 D1 DE 17 00 D3 D2 46 17 00 D3 D2 AE 17 00 D3 D3 16 17
00 D3 D3 7E 17 00 D3 D3 E6 17 00 D3 D4 4E 17 00 D4 4D 2B 17 00 D4 4D 93
17 00 D4 63 CF 17 00 D4 D4 3C 17 00 D4 D4 A4 17 00 D4 D5 0C 17 00 D4 D5
74 17 00 D4 D5 DC 17 00 D4 D6 44 17 00 D4 D6 AC 17 00 D4 D7 14 17 00 D4
D7 7C 17 00 D4 D7 E4 17 00 D4 D8 4C 17 00 D4 D8 B4 17 00 D4 D9 1C 17 00
D4 D9 84 17 00 D4 D9 EC 17 00 D4 DA 54 59 00 DF 40 DD 57 00 DF 52 96 5B
00 DF 56 0B 5B 00 DF 56 73 5B 00 DF 56 DB 5B 00 DF 57 43 5B 00 DF 57 AB
57 00 DF 6C F5 57 00 DF 6D 5D 57 00 DF 6D C5 57 00 DF 6E 2D 57 00 DF 6E
95 57 00 DF 6E FD 57 00 DF 6F 65 5B 00 DF 9F ED 5B 00 DF A0 55 5B 00 DF
A0 BD 5B 00 DF A1 25 5B 00 DF A1 8D 5B 00 DF A1 F5 5B 00 DF A2 5D 5B 00
DF AB 10 5B 00 DF AB 78 5B 00 DF AB E0 5B 00 DF AC 48 5B 00 DF AC B0 5B
00 DF AD 18 5B 00 DF AD 80 5B 00 DF AD E8 5B 00 DF AE 50 5B 00 DF AE B8
5B 00 DF AF 20 5B 00 DF AF 88

19.11 : Data for the run # 11

rpm = 800, vane angle = 22°, replicate # 3

41 00 CE FD 76 41 00 CE FD DE 41 00 CE FE 46 41 00 CE FE AE 41 00 CE FF
16 41 00 CE FF 7E 45 00 CF 0E B2 45 00 CF 0F 1A 45 00 CF 0F 82 45 00 CF
0F EA 45 00 CF 10 52 45 00 CF 10 BA 45 00 CF 11 22 45 00 CF 11 8A 45 00
CF 11 F2 45 00 CF 12 5A 45 00 CF 12 C2 45 00 CF 13 2A 45 00 CF 27 CF 45
00 CF 28 37 45 00 CF 28 9F 45 00 CF 29 07 45 00 CF 29 6F 45 00 CF 29 D7
45 00 CF 2A 3F 45 00 CF 2A A7 45 00 CF 2B 0F 45 00 CF 2B 77 45 00 CF 2B
DF 45 00 CF 2C 47 45 00 CF 2C AF 45 00 CF 2D 17 45 00 CF 2D 7F 45 00 CF
2D E7 45 00 CF 2E 5A 45 00 CF 2E CD 45 00 CF 2F 35 45 00 CF 2F 9D 45 00
CF 30 10 45 00 CF 30 78 45 00 CF 30 E0 45 00 CF 31 48 41 00 CF 43 90 41
00 CF 43 F8 41 00 CF 44 60 41 00 CF 44 C8 41 00 CF 45 30 41 00 CF 45 98
50 00 D2 D2 47 50 00 D2 D2 AF 50 00 D2 D3 D2 50 00 D2 D5 B0 50 00 D2 D6
18 56 00 D2 D9 09 4C 00 D2 D9 71 4C 00 D2 DA EC 4C 00 D2 DB 54 50 00 D2
DD 69 50 00 D2 E1 DB 50 00 D2 E2 43 50 00 D2 E2 AB 50 00 D2 E9 90 50 00
D2 E9 F8 50 00 D2 EA 60

19.12 : Data for the run # 12

rpm = 1000, vane angle = 22°, replicate # 3

24 01 58 72 D8 24 01 58 77 D9 33 01 5B 9A 9D 33 01 5B 9B 05 33 01 5B 9F
FB 33 01 5B A0 63 37 01 5C EE 08 37 01 5C EE 70 37 01 5C F3 7C 37 01 5C
F3 E4 37 01 5C F4 4C 2F 01 5D BF B4 2F 01 5D C0 1C 2F 01 5D CE 02 2F 01
5D CE 6A 2F 01 5D CE D2 2F 01 5D CF 3A 41 01 5E FE E1 41 01 5E FF 49 41
01 5E FF B1 41 01 5F 00 49 41 01 5F 1A C6 45 01 5F 20 A3 45 01 5F 21 0B
45 01 5F 21 73 45 01 5F 21 DB 45 01 5F 27 E4 45 01 5F 28 4C 45 01 5F 28
B4 45 01 5F 29 1C 45 01 5F 29 84 45 01 5F 29 EC 45 01 5F 2A 54 45 01 5F
2A BC 45 01 5F 2B 24 45 01 5F 2B 8C 45 01 5F 2B F4 45 01 5F 2C 5C 45 01
5F 2C C4 45 01 5F 2D 2C 45 01 5F 2D 94 45 01 5F 2D FC 45 01 5F 2E 64 45
01 5F 2E CC 45 01 5F 2F 34 45 01 5F 2F 9C 45 01 5F 30 04 45 01 5F 30 6C
45 01 5F 30 D4 45 01 5F 31 3C 45 01 5F 31 A4 45 01 5F 32 0C 45 01 5F 32
74 45 01 5F 32 DC 45 01 5F 33 44 45 01 5F 33 AC 45 01 5F 34 14 45 01 5F
34 7C 45 01 5F 34 E4 45 01 5F 35 4C 45 01 5F 35 B4 45 01 5F 36 1C 45 01
5F 36 84 47 01 5F 43 57 47 01 5F 43 BF 47 01 5F 44 27 47 01 5F 44 8F 47
01 5F 44 F7 49 01 5F 49 8A 49 01 5F 4B 10 54 01 61 E7 52 54 01 61 E7 BA
54 01 62 0F 09 54 01 62 0F 71 54 01 62 0F D9 54 01 62 10 41 54 01 62 10
A9 54 01 62 11 11 54 01 62 11 79 54 01 62 11 E1 54 01 62 12 49 54 01 62
12 B1 54 01 62 13 19 54 01 62 13 81 54 01 62 13 E9 54 01 62 14 51 54 01
62 14 C4 50 01 62 8B 2A 50 01 62 8D AD 4C 01 63 32 32 4C 01 63 34 E1 4C
01 63 38 77 4C 01 63 3C BD 4C 01 63 3D 25 4C 01 63 B9 16 4C 01 63 BD EB

19.13 : Data for the run # 13

rpm = 800, vane angle = 33°, replicate # 1

30 00 D7 87 52 01 01 17 08 7E 01 01 17 08 E6 01 01 17 09 4E 01 01 17 12
64 01 01 17 12 CC 01 01 17 13 34 01 01 17 13 9C 01 01 17 14 04 01 01 17
34 38 01 01 17 5F 1F 01 01 17 5F 87 01 01 17 5F EF 01 01 17 60 57 01 01
17 60 BF 01 01 17 61 27 01 01 17 A3 69 01 01 17 A3 D1 01 01 17 A4 39 01
01 17 A4 A1 01 01 17 A5 09 01 01 17 A5 71 01 01 17 A5 D9 01 01 17 A6 41
01 01 17 A6 A9 01 01 17 A7 11 01 01 17 A7 79 01 01 17 A7 E1 01 01 17 A8
49 01 01 17 A8 B1 01 01 17 A9 19 01 01 17 A9 81 01 01 17 A9 E9 01 01 17
AA 51 01 01 17 AA B9 01 01 17 AB 21 01 01 17 AB 89 01 01 17 AB F1 01 01
17 AC 59 01 01 17 AC C1 01 01 17 AD 29 01 01 17 AD 91 01 01 17 AD F9 01
01 17 AE 61 01 01 17 AE C9 01 01 17 AF 31 01 01 17 AF 99 01 01 17 B0 01
01 01 17 B0 69 01 01 17 B0 D1 01 01 17 B1 39 01 01 17 B1 A1 4C 01 25 B4
20 4C 01 25 B6 AE 40 01 26 AA A6 40 01 26 AB 0E 40 01 26 AB 76 40 01 26
BC A0 40 01 26 BD 08 40 01 26 BD 9C 40 01 26 C2 19 40 01 26 C8 C7 40 01
26 D3 B6 40 01 26 DB CF 40 01 26 F3 76 40 01 26 F3 DE 40 01 26 F4 46 5F
01 2E 56 45 5F 01 2E 56 AD 5F 01 2E 5E FD 57 01 30 2C F4 57 01 30 2D 5C
57 01 30 2D C4 57 01 30 2E 2C 57 01 30 A5 42 57 01 30 A5 AA 57 01 30 A6
12 57 01 30 A6 7A 57 01 30 A6 E2 57 01 30 A7 4A

19.14 : Data for the run # 14

rpm = 1000, vane angle = 33°, replicate # 1

1F 00 CE 10 33 1F 00 CE 10 9B 1F 00 CE 11 03 1F 00 CE 11 6B 1F 00 CE 11
D3 1F 00 CE 12 3B 1F 00 CE 12 A3 1F 00 CE 13 0B 1F 00 CE 13 73 1F 00 CE
13 DB 1F 00 CE 14 43 1F 00 CE 14 AB 1F 00 CE 2E 57 1F 00 CE 2E BF 1F 00
CE 2F 27 1F 00 CE 2F 8F 1F 00 CE 2F F7 1F 00 CE 30 5F 1F 00 CE 30 C7 1F
00 CE 31 2F 1F 00 CE 31 97 1F 00 CE 31 FF 1F 00 CE 32 67 1F 00 CE 32 CF
1F 00 CE 33 37 1F 00 CE 33 9F 1F 00 CE 34 07 30 00 D0 B5 D1 32 00 D0 BC
CC 36 00 D0 BD 34 36 00 D0 C2 DA 36 00 D0 C3 42 3E 00 D1 06 69 3E 00 D1
06 D1 3E 00 D1 0B FE 3E 00 D1 13 88 3E 00 D1 18 89 3E 00 D1 18 F1 3E 00
D1 19 59 51 00 D8 7B B7 53 00 D8 7C 1F 53 00 D8 7C 87 53 00 D8 7C EF 53
00 D8 7D 57 53 00 D8 7D BF 53 00 D8 7E 27 53 00 D8 E7 30 53 00 D8 E7 98
53 00 D8 E8 00 53 00 D8 E8 68 53 00 D8 E8 D0 53 00 D8 E9 38 49 00 D8 EF
8E 49 00 D8 EF F6 49 00 D8 F0 5E 49 00 D8 F0 C6 49 00 D8 F1 2E 49 00 D8
F1 96 49 00 D8 F1 FE 49 00 D9 1A FA 49 00 D9 1B 62 49 00 D9 1B CA 49 00
D9 1C 32 49 00 D9 1C 9A 49 00 D9 1D 02 49 00 D9 1D 6A 49 00 D9 1D D2 5F
00 DA 46 41 5F 00 DA 46 A9 5F 00 DA 47 11 5F 00 DA 47 79 5F 00 DA 47 E1
5F 00 DA 48 49 5F 00 DA 48 B1 5F 00 DA 49 19 5F 00 DA 49 81 5F 00 DA 49
E9 5F 00 DA 4A 51 5F 00 DA 4A B9 5F 00 DA 4B 21 5F 00 DA 4B 89 5F 00 DA
4B F1

19.15 : Data for the run # 15

rpm = 800, vane angle = 33°, replicate # 2

11 00 E4 28 B5 11 00 E4 29 1D 11 00 E4 29 85 11 00 E4 29 ED 11 00 E4 2A
55 11 00 E4 2A BD 11 00 E4 2B 25 11 00 E4 2B 8D 11 00 E4 2B F5 11 00 E4
2C 5D 11 00 E4 2C C5 11 00 E4 2D 2D 11 00 E4 2D 95 11 00 E4 2D FD 11 00
E4 2E 65 11 00 E4 2E CD 11 00 E4 2F 35 11 00 E4 2F 9D 13 00 E4 46 B5 11
00 E4 47 1D 11 00 E4 47 85 13 00 E4 47 ED 13 00 E4 48 55 11 00 E4 48 BD
11 00 E4 49 25 13 00 E4 49 8D 13 00 E4 49 F5 11 00 E4 4A 5D 11 00 E4 4A
C5 13 00 E4 4B 2D 13 00 E4 4B 95 24 00 E7 F6 4D 24 00 E8 04 84 24 00 E8
04 EC 24 00 E8 05 54 24 00 E8 05 BC 24 00 E8 06 24 24 00 E8 09 41 24 00
E8 09 A9 24 00 E8 0A 11 24 00 E8 0A 79 24 00 E8 0E 0F 24 00 E8 26 45 24
00 E8 26 AD 24 00 E8 27 15 24 00 E8 27 7D 24 00 E8 27 E5 4C 00 F3 6A 42
4C 00 F3 6A AA 4C 00 F3 6D 43 4C 00 F3 74 07 4C 00 F3 78 2C 4C 00 F3 7A
C5 4C 00 F3 7D 5E 4C 00 F3 8B 86 4C 00 F3 8B EE 4C 00 F3 8C 56 4C 00 F3
8C BE 4C 00 F3 8E 44 4C 00 F3 8E AC 4C 00 F3 8F 14 4C 00 F3 8F 7C 4C 00
F3 8F E4

19.16 : Data for the run # 16

rpm = 1000, vane angle = 33°, replicate # 2

24 00 CE 3A 4D 24 00 CE 3A B5 24 00 CE 45 15 3F 00 D6 E8 0E 3F 00 D6 E8
76 3F 00 D6 E8 DE 3F 00 D6 E9 46 3F 00 D6 E9 AE 3F 00 D6 EA 16 3F 00 D6
EA 7E 3F 00 D6 EA E6 3F 00 D6 EB 4E 3F 00 D6 EB B6 3F 00 D6 EC 1E 3F 00
D6 EC 86 3F 00 D6 EC EE 3F 00 D6 ED 56 3F 00 D7 0E 28 3F 00 D7 0E 90 3F
00 D7 0E F8 3F 00 D7 0F 60 3F 00 D7 0F C8 3F 00 D7 39 4F 3F 00 D7 39 B7
3F 00 D7 3A 1F 3F 00 D7 3A 87 3F 00 D7 3A EF 3F 00 D7 3B 57 3F 00 D7 3B
BF 3F 00 D7 64 75 3F 00 D7 64 DD 3F 00 D7 65 45 3F 00 D7 65 AD 3F 00 D7
66 15 3F 00 D7 66 7D 3F 00 D7 66 E5 3F 00 D7 67 4D 3F 00 D7 67 B5 3F 00
D7 68 1D 3F 00 D7 68 85 3F 00 D7 68 ED 3F 00 D7 69 55 3F 00 D7 69 BD 3F
00 D7 6A 25 3F 00 D7 6A 8D 3F 00 D7 6A F5 50 00 DB EE 36 50 00 DB F2 3A

19.17 : Data for the run # 17

rpm = 800, vane angle = 33°, replicate # 3

01 00 EA D3 34 01 00 EA D3 9C 01 00 EA D4 04 01 00 EA D4 6C 01 00 EA E6
9E 00 00 ED 4B 08 00 00 ED 4B 70 04 00 ED 4C 04 04 00 ED 50 E4 04 00 ED
51 4C 00 00 ED 51 B4 00 00 ED 52 1C 27 00 F4 24 04 27 00 F4 24 6C 27 00
F4 24 D4 27 00 F4 25 3C 27 00 F4 25 AF 27 00 F4 4B 42 27 00 F4 4B AA 27
00 F4 4C 12 27 00 F4 4C 7A 27 00 F4 4C E2 27 00 F4 4D 4A 27 00 F4 4D B2
49 00 FE CE 6D 49 00 FE CE D5 49 00 FE CF 3D 49 00 FE CF A5 49 00 FE D0
0D 49 00 FE D0 75 45 00 FE E9 A8 47 00 FE EA 10 47 00 FE EA 83 47 00 FE
EA EB 47 00 FE EB 53 47 00 FE EB BB 47 00 FE EC 23 47 00 FE EC 8B 47 00
FE EC F3 47 00 FE ED 5B 47 00 FE ED C3 47 00 FE EE 2B 47 00 FE EE 93 47
00 FE EE FB 47 00 FE EF 63 47 00 FE EF CB 47 00 FE F0 33 47 00 FE F0 9B
4F 00 FE F1 03 4F 00 FE F1 6B 4F 00 FE F1 D3 4F 00 FE F2 3B 49 00 FE F2
A3 49 00 FE F3 0B 49 00 FE F3 73 49 00 FE F3 DB 49 00 FE F4 43 49 00 FE
F4 AB 57 00 FF 47 08 57 00 FF 6E 95 57 00 FF 6E FD

19.18 : Data for the run # 18

rpm = 1000, vane angle = 33°, replicate # 3

18 00 E8 EA 5F 18 00 E8 F1 DE 18 00 E9 A7 5C 18 00 E9 A7 C4 18 00 E9 C1
7B 18 00 E9 C1 E3 21 00 ED 5C 35 23 00 ED 5C 9D 23 00 ED 6D 6F 23 00 ED
6D D7 53 00 ED B3 DB 53 00 ED CB 8D 3F 00 EF 5F C4 3F 00 EF 60 2C 3F 00
EF 60 94 3F 00 EF 60 FC 3F 00 EF 61 64 3F 00 EF 61 CC 3F 00 EF 62 34 3F
00 EF 62 9C 3F 00 EF 63 04 3F 00 EF 63 6C 3F 00 EF 63 D4 3F 00 EF 68 EB
3F 00 EF 69 53 3F 00 EF 69 BB 41 00 F1 EA EB 41 00 F1 EB 53 41 00 F1 EB
BB 41 00 F1 EC 23 41 00 F1 EC 8B 4D 00 FB 48 2F 4F 00 FB 48 97 4F 00 FB
48 FF 4F 00 FB 49 67 4F 00 FB 49 CF 4F 00 FB 4A 37 4F 00 FB 4A 9F 4F 00
FB 4B 07 4F 00 FB 4B 6F 4F 00 FB 4B D7 4F 00 FB 4C 3F 4F 00 FB 4C A7 4F
00 FB 4D 0F 4F 00 FB 4D 77 4F 00 FB 4D DF 4F 00 FB 4E 47 4F 00 FB 4E AF
4F 00 FB 4F 17 4F 00 FB 4F 7F 4F 00 FB 4F E7 4F 00 FB 50 4F 4F 00 FB 50
B7 4F 00 FB 51 2A 4F 00 FB 56 8E 4F 00 FB 57 01 4F 00 FB 57 69 4F 00 FB
57 D1 4F 00 FB 58 39 4F 00 FB 58 A1 4F 00 FB 59 09 4F 00 FB 59 71 4F 00
FB 59 D9 4F 00 FB 5A 41 4F 00 FB 5A A9 4F 00 FB 5B 11 4F 00 FB 5B 79 4F
00 FB 5B E1 4F 00 FB 5C 49 4F 00 FB 5C B1 4F 00 FB 5D 19 4F 00 FB 5D 81
4F 00 FB 72 89 4F 00 FB 72 F1 4F 00 FB 73 59 4F 00 FB 73 C1 4F 00 FB 74
29 4F 00 FB 74 91 4F 00 FB A9 DE 4F 00 FB AA 46 4F 00 FB AA AE 4F 00 FB
AB 16 4F 00 FB AB 7E 4F 00 FB AB E6 4F 00 FB AC 4E 4F 00 FB AC B6 4F 00
FB AD 1E 4F 00 FB AD 86